THE OBSERVATORY

SOME SYSTEMATICS OF CHROMOSPHERIC CALCIUM II H AND K EMISSION AMONG F, G, AND K DWARF STARS

By Graeme H. Smith
University of California Observatories/Lick Observatory

and Anja K. Redenbaugh & Ashley Jones
Department of Physics, University of California, Santa Cruz

Emission in the centres of the Ca II H and K lines has become a much-employed tracer of chromospheric activity among late-type dwarf stars. Building upon the Mount Wilson HK project, standardized measurements of R'_{HK}, the ratio of flux in the chromospheric emission component of the H and K lines to the bolometric flux, have been made by a number of large observing programmes, sometimes as a by-product of searches for extra-solar planetary systems. By using the results of those programmes, values of $\log R'_{HK}$ have been compiled from the literature for over 2600 dwarfs. The majority of the stars have colours in the range $0^m\!\cdot\!4 \leq (B-V) \leq 1^m\!\cdot\!0$, masses of $0\!\cdot\!8\ M_\odot$ to $1\!\cdot\!5\ M_\odot$, and metallicities in the range $-0\!\cdot\!8 \leq$ [Fe/H] $\leq +0\!\cdot\!3$. The spread in emission among typical dwarfs is $-5\!\cdot\!2 \leq \log R'_{HK} \leq -4\!\cdot\!2$ regardless of colour. Two trends formerly noted in the literature are confirmed with this larger data set: the minimum $\log R'_{HK}$ shows a modest decrease with increasing [Fe/H], and with increasing luminosity above the Zero-Age Main Sequence. For dwarfs with $(B-V)$ colours similar to the Sun and $-4\!\cdot\!7 \leq R'_{HK} \leq -4\!\cdot\!2$, there is a correlation between emission and rotation speed that is approximately of the form $R'_{HK} \propto (v \sin i)^{1/2}$, albeit with notable scatter. The behaviour of $\log R'_{HK}$ *versus* $v \sin i$ varies with $(B-V)$ colour in a manner that is qualitatively consistent with an anticorrelation between the intensity of emission and the Rossby number.

Introduction

The detection of solar-like activity cycles among dwarf stars other than the Sun was made by Wilson[1] through measurements of the intensity of chromospheric emission features in the cores of the Ca II *H* and *K* lines, carried out using the coudé scanner on the Mount Wilson 100-in telescope. That initial demonstration of the utility of the *H* and *K* emission lines for monitoring stellar activity cycles was the forerunner to a more extensive survey of the *H* and *K* features using a photon-counting spectrophotometer on the Mount Wilson 60-inch telescope[2]. Measurements were made of photomultiplier counts recorded in passbands of 1 Å FWHM centred on the *H*- and *K*-line cores, as well as two broader comparison bands covering the wavelength ranges 3891–3911 Å and 3991–4011 Å. Instrumental counts were used to form an index denoted *S*, which constitutes the ratio between the detector counts in the combined *H*- and *K*-line cores and those in the combined comparison bands. The Mount Wilson observing system was used to make both a snapshot survey of Ca II *H+K* emission in dwarf stars of the solar neighbourhood[3], as well as a study of rotation-induced variations in emission strength[4,5].

Thus began the Mount Wilson *HK* project that has led to large studies not only of stellar activity cycles but also the distribution of activity among dwarf stars[6–11]. Analogous surveys were instituted by several other groups[12–15]. In addition, Ca II *H* and *K* emission measurements have been a by-product of extensive extra-solar-planet searches[16–18]. As a result of those projects there is now a large data base of consistent Ca II *H+K* flux data available in the literature. In this paper, we have sought to use such data to study some systematics of chromospheric *H* and *K* emission among dwarf stars.

The calcium-emission-data sources

The most useful quantity for our purposes is conventionally denoted R'_{HK}, and is the ratio between the combined flux in the chromospheric *H* and *K* emission lines and the stellar bolometric flux. Values of log R'_{HK} have been obtained from a variety of literature sources. A methodology for deriving R'_{HK} from Mount Wilson *HK* observations was developed by Middelkoop[19] and Noyes *et al.*[20], with the latter authors providing a tabulation of this parameter for 100 dwarf stars. Other useful tabulations based directly on Mount Wilson *HK* data are given by Soderblom[21] and Soderblom, Duncan & Johnson[22]. Those works served as the earliest sources that we have used in compiling an extensive set of log R'_{HK} measurements. The largest catalogues, from which most R'_{HK} values have been drawn, are those of Henry *et al.*[13], Gray *et al.*[14,15], Wright *et al.*[16], and Jenkins *et al.*[17,18]. In addition, values of log R'_{HK} have been gleaned from a variety of other studies[23–60], which typically contain data for much smaller numbers of stars. The majority of stars in the resultant compilation are dwarfs of luminosity class V, with some class IV stars also being included.

There is considerable overlap in stars between the larger catalogues of R'_{HK} indices, and comparisons between various surveys have previously been discussed by Jenkins *et al.*[18]. The compilation of Henry *et al.*[13] was taken as defining the standard Mount Wilson log R'_{HK} system; their paper in fact gives a tabulation of 'standard' values. A plot of values from Gray *et al.*[15] *versus* those from Henry *et al.*[13] is shown in Fig. 1, where it can be seen that there is a systematic difference between the two catalogues. Comparisons were made between the log R'_{HK} measurements of Henry *et al.*[13] and six other of the largest data sets available. The results are summarized in Table I, wherein is listed the
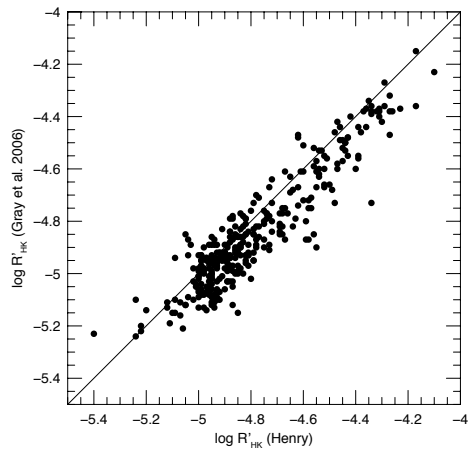
FIG. 1

The Ca II *H* and *K* emission parameter log R'_{HK} as measured by Gray *et al.*[15] *versus* values from Henry *et al.*[13] for stars in common between the two surveys.

value of the mean difference $\Delta R_{HK} = \langle$log R'_{HK} (Henry) − log R'_{HK} (other)$\rangle$, the standard deviation σ, the standard deviation in this mean σ_m, and the number of stars N on which these statistics are based. The only two data sets which are considered here to have a systematic difference from that of Henry *et al.*[13] are those of Gray *et al.*[14,15].

A collection of log R'_{HK} values was formulated by averaging together the measurements from the available sources. All sources were weighted equally. All values of log R'_{HK} from Gray *et al.*[14] were increased by 0·11 in order to place them on the same system as Henry *et al.*[13], whereas a constant of 0·06 was added to the values of Gray *et al.*[15], in line with the offsets given in Table I. The resulting homogenized compilation of log R'_{HK} values, which totals 2691 stars, is referred to as the *Ca emission catalogue* throughout this paper. Colours in the Johnson $(B − V)$ system were obtained from the on-line version of *The General Catalogue of Photometric Data*[61] (accessed *via* the web site http://obswww.unige. ch/gcpd/gcpd.html).

TABLE I

Comparisons between sources of log R'_{HK} data

Source ref.	ΔR_{HK}*	σ	σ_m	N
14	0·109	0·068	0·016	17
15	0·058	0·086	0·005	337
16	0·011	0·074	0·008	94
17	−0·024	0·092	0·010	78
18	0·027	0·090	0·016	32
20	0·022	0·105	0·018	34

*Mean value of log R'_{HK} (Henry *et al.*[13]) − log R'_{HK} (other source).

Chromospheric activity among late-type dwarfs can be variable in time as a consequence of both short-timescale changes in active-region coverage of a stellar disc as well as long-term activity cycles. Such effects can cause variability in the log R'_{HK} value of a star. Indeed, it was such variability that provided Wilson[1] with the means to identify analogues of the solar-activity cycle on other stars. Consequently, the standard deviations σ listed in Table I reflect not only the measurement errors of the various R'_{HK} surveys, but also likely contain a component due to stellar variability. In turn, σ provides one estimate for an upper limit on the amount by which log R'_{HK} may vary intrinsically among late-type F, G, and K dwarfs. From the work of Radick *et al.*[62] and Lockwood *et al.*[63] intrinsic variability may typically amount to r.m.s(log R'_{HK}) ~ ±0·03, whereas values of σ in Table I are 0·07–0·11.

The behaviour of log R'_{HK} as a function of $(B-V)$ colour for stars in the *Ca emission catalogue* is shown in Fig. 2. The majority of stars have emission strengths in the range $-5·2 \lesssim$ log $R'_{HK} \lesssim -4·3$. There is a noticeable concentration in the region of the diagram defined by $(B-V) \lesssim 0^{m}·8$ and log $R'_{HK} \lesssim -4·75$. Such stars are referred to as "lower branch" or chromospherically "old" stars by Vaughan[64]. Throughout the remainder of this paper the term 'low activity' will be used in reference to dwarfs having log $R'_{HK} \lesssim -4·75$. By comparison, dwarfs in the Hyades cluster[65] typically have emission levels of log R'_{HK} ~ $-4·4$ to $-4·5$. There are very few stars in the *Ca emission catalogue* with $(B-V) > 1^{m}·0$ which are in a low-activity state. Whether that is an observational selection effect is not known; however, attention will largely be restricted to stars with $(B-V) \lesssim 1^{m}·0$ throughout this paper.

Stars with log $R'_{HK} > -4·0$ have the highest levels of activity in our compilation. Use of *Simbad* reveals that most of those stars fall into several categories: BY Dra
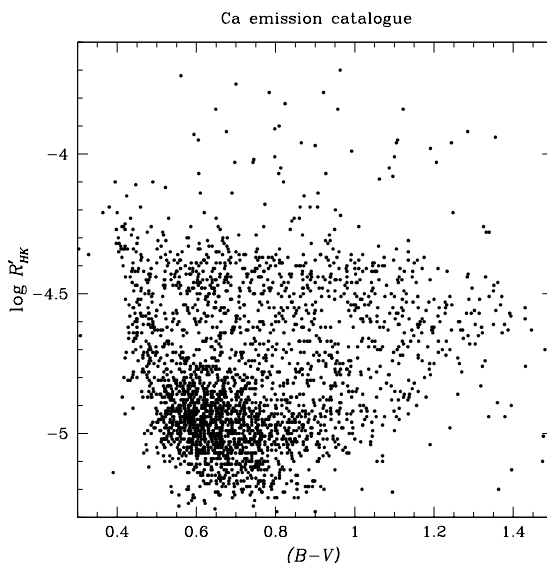

Ca emission catalogue

FIG. 2

The Ca II *HK* emission parameter log R'_{HK} *versus* $(B-V)$ colour for stars in the *Ca emission catalogue*.

variable stars (28%), pre-main-sequence stars (24%), RS CVn stars (16%), together with much smaller fractions of other types of variables, flare stars, and spectroscopic binaries. Hence, such high levels of activity are indicative of particular circumstances, and are not typical of dwarf stars older than the Hyades. The presence of RS CVn stars in the *Ca emission catalogue* indicates that the literature sources drawn upon do not exclusively comprise dwarf stars, but some stars in post-main-sequence and subgiant phases of evolution are also included.

In the activity range $-4\cdot2 \leq \log R'_{HK} \leq -4\cdot0$ the fractions of BY Dra variable stars, pre-main-sequence stars, and RS CVn stars are 15%, 28%, and 18%, respectively, another 15% of the stars are simply labelled as "Variable Star" by *Simbad*, and there are no flare stars. With decreasing emission strength in the range $-4\cdot4 \leq \log R'_{HK} \leq -4\cdot2$, which is slightly higher than levels typical among Hyades cluster dwarfs, there are again no flare stars, the fraction of RS CVn stars has dropped to 1%, while BY Dra variables and pre-main-sequence stars constitute 17% and 19% of the group, respectively. What might be termed 'normal' dwarfs are becoming more prevalent at that activity level, with 40% of such stars in our compilation being designated as either a "Star" or a "High Proper-Motion Star" by *Simbad*. By contrast, there are no such 'normal' stars among those with $\log R'_{HK} > -4\cdot0$ in the *Ca emission catalogue*, and only 8% in the $-4\cdot2 \leq \log R'_{HK} \leq -4\cdot0$ activity range. Thus, upon a decrease in activity from the maximum levels observed, the fraction of 'normal' stars in the *Ca emission catalogue* increases, while RS CVn and flare stars mostly have emission indices of $\log R'_{HK} > -4\cdot2$.

Calcium emission among dwarfs with respect to mass, evolution, and metallicity

The Geneva–Copenhagen survey of solar-neighbourhood stars by Nordström *et al.*[66] derived fundamental parameters for some 14 000 F and G dwarfs observed by *Hipparcos*. Their survey provides ancillary information for a great majority of stars in the *Ca emission catalogue*. Effective temperatures and metallicities were obtained from calibrations of the Strömgren photometric indices $b-y$, c_1, and m_1. Stellar masses were derived *via* fits of Padova isochrones[67,68] to the combined values of $\log T_{eff}$, M_V, and [Fe/H] for each star. The absolute magnitude M_V and stellar mass for stars in the *Ca emission catalogue* are both taken from Nordström *et al.*[66] where available.

By combining the *Ca emission catalogue* with the stellar parameters given by Nordström *et al.*[66], an expanded data base for 1937 stars is obtained. An M_V versus $(B-V)$ colour–magnitude diagram for this *merged sample* is shown in Fig. 3. A subset of the stars appears to have evolved more than one magnitude away from the Zero-Age Main Sequence (ZAMS). Compared to the larger *Ca emission catalogue*, one of the effects of forcing an overlap with the Nordström *et al.*[66] data base is to limit the stars in colour, and there are very few stars in the *merged sample* having $(B-V) > 1^m\cdot0$.

The majority of stars in the *merged sample* have isochrone masses M in the range $0\cdot8$–$1\cdot6$ $M_\odot$. A plot of $\log R'_{HK}$ *versus* M is given in Fig. 4. Both a high- and a low-activity branch of stars are evident throughout the entire mass range covered by the *merged sample*. There is some indication that the mean value of $\log R'_{HK}$ for the low-activity branch decreases with increasing mass, such that a typical low-activity dwarf of mass $M \sim 0\cdot8$ $M_\odot$ has $-5\cdot0 < \log R'_{HK} < -4\cdot75$, whereas a substantial fraction of low-activity stars of $1\cdot4$–$1\cdot5$ $M_\odot$ have $\log R'_{HK} < -5\cdot0$. The trend, however, may not be related to mass so much as to evolution away from the main sequence.

merged sample (Ca + Nordstrom *et al.*)

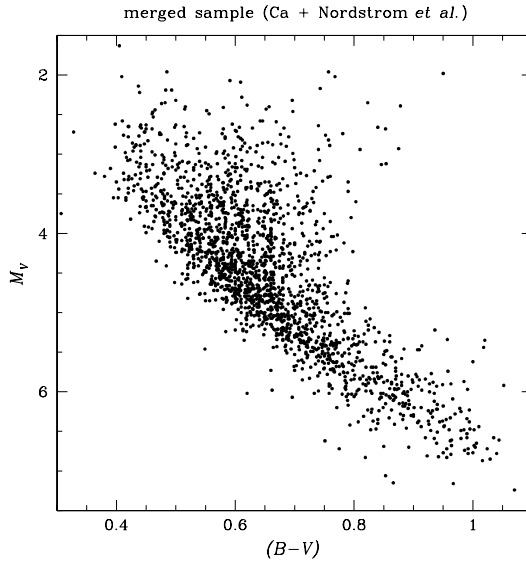

FIG. 3

The $(M_V, B - V)$ colour–magnitude diagram of stars in the *merged sample*, defined by having not only log R'_{HK} measurements but also absolute magnitudes from the catalogue of Nordström *et al.*[66].
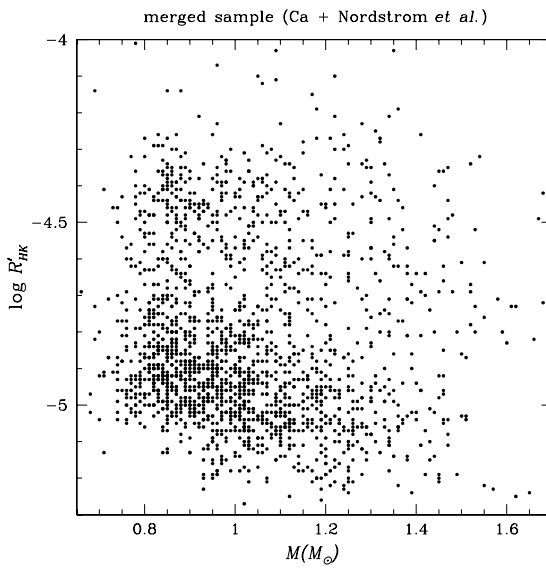
merged sample (Ca + Nordstrom *et al.*)

FIG. 4

The Ca II *HK* emission index log R'_{HK} *versus* isochrone mass from Nordström *et al.*[66] for stars in the *merged sample*.

The Nordström *et al.*[66] catalogue gives a number of parameters in addition to those noted above. A particularly useful one for the present discussion is the difference δM_V between the absolute magnitude of each star and that of the theoretical ZAMS at the same colour and metallicity of that star. The δM_V parameter is plotted *versus* the isochrone masses in Fig. 5. Most of the stars with $M > 1\cdot4\ M_\odot$ are found to be more than $0^m\cdot5$ brighter than the ZAMS, and Fig. 5 illustrates that some of the most massive stars in the *merged sample* are also among the most evolved.

A plot of log R'_{HK} *versus* δM_V is shown in Fig. 6. The diagram again shows both a high- and a low-activity branch of stars. Among the low-activity branch the mean log R'_{HK} decreases with increasing luminosity above the ZAMS, thereby revealing an evolutionary decrease in chromospheric activity as stars evolve away from the ZAMS. Such an effect was first emphasized by Wright[69], who pointed out that many stars formerly thought of as being in solar-like Maunder-minimum states of very low activity were instead stars that were more advanced in their evolution than the Sun. Since many of the highest-mass stars in the *merged sample* are also among the most removed from the ZAMS, the trend seen between Ca emission and mass among the low-activity stars in Fig. 4 may therefore be the product of an evolutionary decrease in activity.

The distribution of metallicities among the dwarfs in the *merged sample* is illustrated in Fig. 7 *via* a plot of log R'_{HK} *versus* photometric [Fe/H] from Nordström *et al.*[66]. A majority of the dwarfs have metallicities in the range $-0\cdot4 <$ [Fe/H] $< +0\cdot3$, although some are as metal-poor as [Fe/H] $= -0\cdot8$. Saar[70] found that the minimum value of the log R'_{HK} index for dwarfs has a metallicity sensitivity, such that it decreases with increasing metallicity. This conclusion is verified by Fig. 7. Such a metallicity effect could affect the interpretation of Fig. 6, and so a separate version of that figure was prepared showing only stars from the *merged sample* with photometric metallicities in the narrow range $-0\cdot2 \leq$ [Fe/H] $\leq 0\cdot0$; it is shown in Fig. 8. Once again, over a more restricted metallicity range, the mean emission among low-activity dwarfs is seen to decrease with advancing evolution away from the main sequence. As noted by Wright *et al.*[69] and Saar[70] the variations of log R'_{HK} with both δM_V and [Fe/H] can complicate the identification of dwarf stars in true Maunder-minimum-like states of very low activity. The former trend is presumably due to a decrease in dynamo activity as a star evolves away from the main sequence and spins down as it increases in radius. The trend with [Fe/H] is complicated. Metal lines blanket the comparison bandpasses used to define the Mount Wilson *HK* spectrophotometric system (see, *e.g.*, Soon *et al.*[71]), however, a metallicity effect is not usually taken into account when converting the *S* index into log R'_{HK}. The systematic trend in Fig. 7 may be (at least partially) a consequence of the lack of a precise metallicity term in that conversion.

Trends with projected rotation velocity

It is has been well documented that the level of chromospheric activity of dwarf stars is correlated with their rotation[20,72]. Our compilation of calcium-emission indices allows that to be documented in a partial way. Ideally it is best to search for correlations between emission flux and actual rotation period, but the latter variable is available for only a small subset of the stars in the *Ca emission catalogue*, and in any event such correlations for dwarf stars have been discussed elsewhere (*e.g.*, Noyes *et al.*[20], Marilli *et al.*[73], Rutten[74], Yun & Park[75]), albeit for smaller samples of dwarfs. What is contributed here is to document the behaviour of log R'_{HK} relative to the projected stellar equatorial rotation

merged sample (Ca + Nordstrom *et al.*)
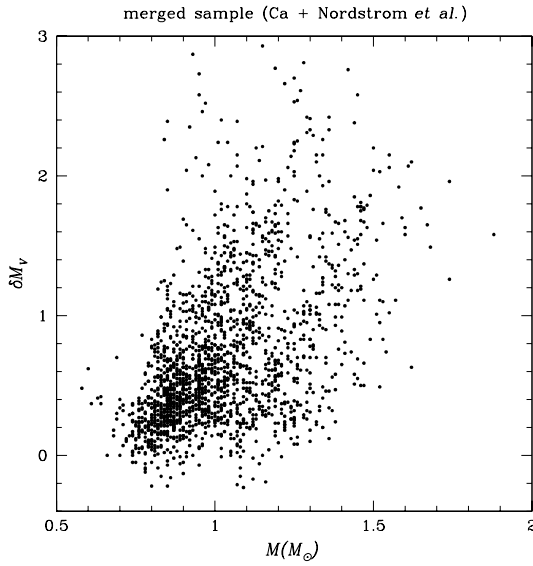
FIG. 5

The magnitude offset δM_V measured relative to the ZAMS *versus* isochrone mass M from Nordström *et al.*[66] for stars in the *merged sample*.

merged sample (Ca + Nordstrom *et al.*)
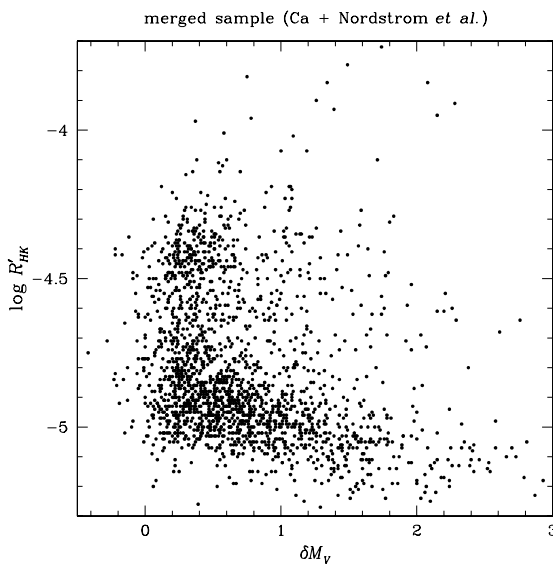
FIG. 6

The Ca II *HK* emission index $\log R'_{HK}$ *versus* magnitude offset δM_V from the ZAMS for stars in the *merged sample*.

merged sample (Ca + Nordstrom *et al.*)

FIG. 7

The *HK* emission index log R'_{HK} *versus* photometric metallicity [Fe/H] from Nordström *et al.*[66] for stars in the *merged sample*.

merged sample for $-0.2 \leqq [Fe/H] \leqq 0.0$

FIG. 8

The Ca II emission index log R'_{HK} *versus* magnitude offset δM_V from the ZAMS for stars in the restricted metallicity range of $-0.2 \leqq [Fe/H] \leqq 0.0$.

speed $v\sin i$, which is available from literature sources for many of the stars in the *Ca emission catalogue*.

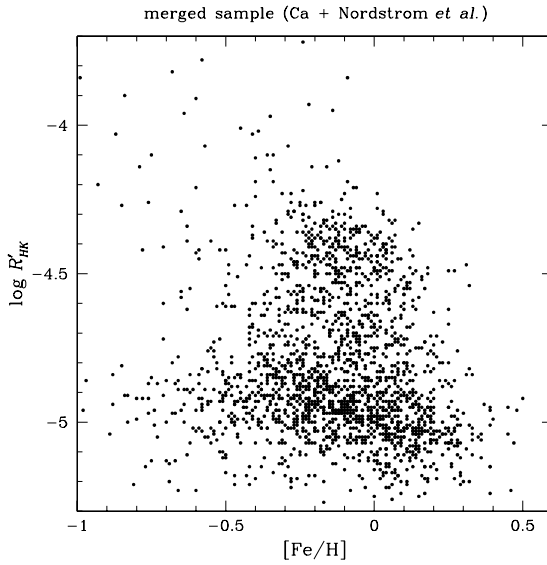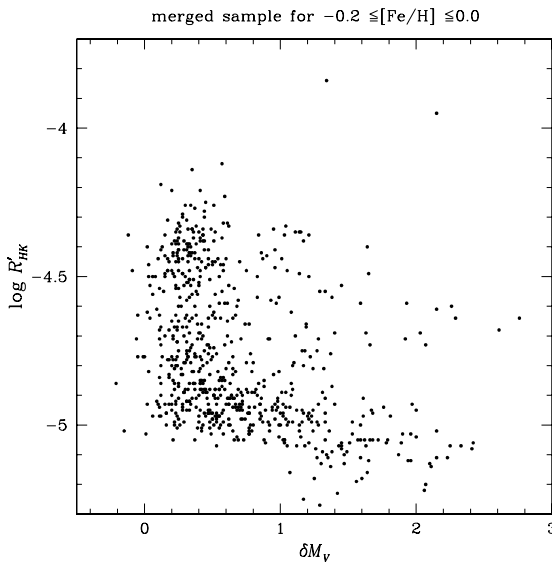Three extensive tabulations of $v\sin i$ measurements for dwarf stars have been utilized. Values presented by Valenti & Fischer[76] have been measured from high-resolution spectra obtained at the Lick Observatory 3-m, *Keck I* 10-m, and *AAT* 3·9-m telescopes. Those observations provide a homogeneous set of $v\sin i$ measurements. The extensive compilation of dwarf-star properties by Holmberg, Nordström & Andersen[77] (denoted below as H07) includes rotation velocities, many of which have been computed from data obtained with the *Coravel*[78] or CfA[79] spectrometers. A third catalogue has also been employed, that of Głębocki, Gnacinski & Stawikowski (denoted G00), which is a compilation of a wide variety of measurements from the literature prior to 2000. It was described by Głębocki & Stawikowski[80], and accessed *via* the web site http://vizier.cfa.harvard.edu/viz-bin/Cat?III/226.

The $v\sin i$ data from the H07 and G00 catalogues are plotted *versus* those of Valenti & Fischer[76] for stars from the *Ca emission catalogue* in Figs. 9 and 10, respectively. In the former figure the two data sets correlate very well down to quite small values of $v\sin i$. By contrast, the G00 rotation velocities correlate notably less well for $v\sin i < 7$ km s^{-1} (Fig. 10). We attribute that to the greater inhomogeneity of the G00 catalogue, as well as an indication that it contains $v\sin i$ values with larger measurement uncertainties.

The above three sources have been used to produce a compilation of $v\sin i$ data for stars in the *Ca emission catalogue*. Rather than take an average rotation velocity for a star that appears in more than one reference, we have instead chosen the value from Valenti & Fischer[76] where it is available. If not, then a value from H07 has been chosen when available. If a star appears in the G00 catalogue, but not the other two, then the G00 value was adopted.
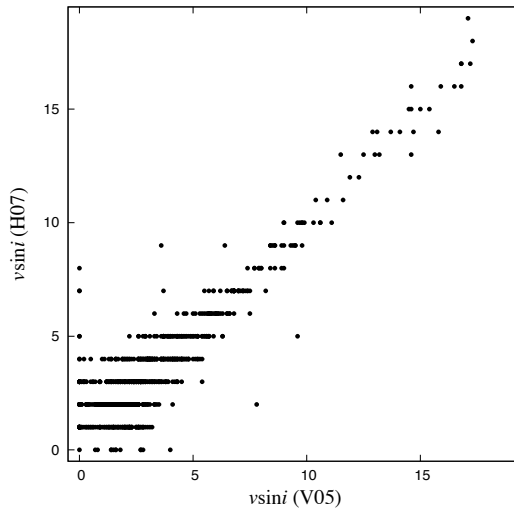

Fig. 9

Rotation velocities from Holmberg, Nordström & Andersen[77] (H07) *versus* measurements from Valenti & Fischer[76] (V05) for stars in the *Ca emission catalogue*.
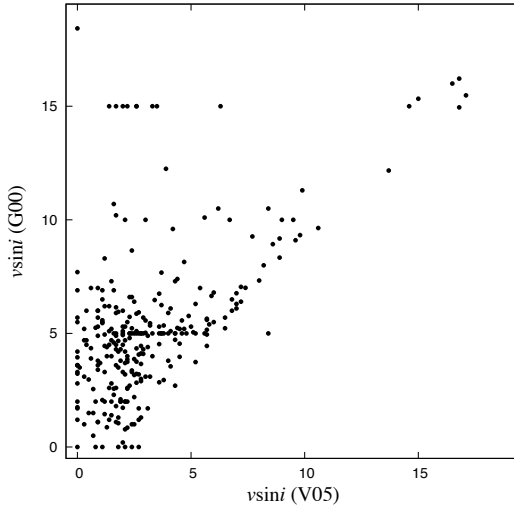
Rotation velocities from Głębocki, Gnacinski & Stawikowski (G00) (see ref. 80) *versus* measurements from Valenti & Fischer[76] (V05) for stars in the *Ca emission catalogue*.

This approach is an attempt to preserve as much as possible the homogeneity of the various data sets. The resultant $v \sin i$ values for stars in the *Ca emission catalogue* are plotted against $(B - V)$ in Fig. 11. Among dwarfs of any particular $(B - V)$ there is a wide range in $v \sin i$, some of which is intrinsic, some of which is measurement error, and some of which is presumed due to differences of the inclination angle i. There is also probably a spread in rotation speed owing to the different ages of the stars depicted in the figure, and the well-documented rotation–age relationship among dwarf stars (*e.g.*, refs. 81–84). Regardless, the average $v \sin i$ appears to increase with decreasing $(B - V)$ among stars with $(B - V) < 0^{\mathrm{m}} \cdot 7$, as expected from studies of the systematics of stellar rotation along the main sequence[85,86,87].

The behaviour of log R'_{HK} *versus* $v \sin i$ is shown in Fig. 12 for stars in the *Ca emission catalogue*. The data show considerable scatter with a broad trend for H and K emission to become stronger with increasing rotation speed above $v \sin i \sim 10$ km s^{-1}. Part of the scatter will be due to observational error as well as differences in the inclination angle i among stars, the former of which makes it particularly difficult to discern trends among slowly rotating stars in such a diagram. Another factor is the difference in $(B - V)$ and mass among the stars plotted. Since the work of Noyes *et al.*[20], the connection between chromospheric activity and stellar rotation has often been expressed by correlating various activity indicators against the Rossby number, which is defined as the ratio between the rotation period and the turnover time near the base of the convection zone (see, for example, Stępień[88] for a discussion). Stellar radius varies with $(B - V)$ along the main sequence, and it can be seen from Fig. 11 that $v \sin i$ also has a systematic variation with colour, at least for stars with $(B - V) < 0^{\mathrm{m}} \cdot 7$. In addition, the convective turnover time is thought on theoretical grounds to vary with effective temperature, or equivalently mass,
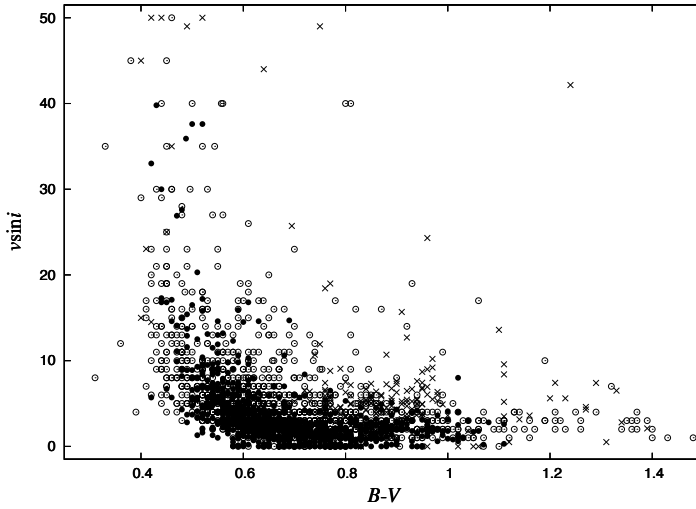
Fig. 11

Rotation velocity $v \sin i$ *versus* $(B - V)$ colour for stars in the *Ca emission catalogue*. Filled circles depict velocity measurements from Valenti & Fischer[76], whereas open circles and crosses show data from the H07 and G00 catalogues, respectively.
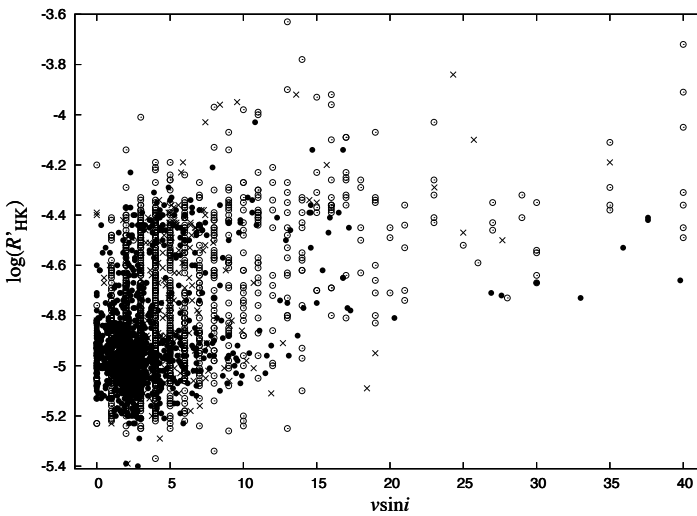
Fig. 12

The emission index $\log R'_{HK}$ *versus* rotation velocity $v \sin i$ for stars in the *Ca emission catalogue* with $v \sin i < 40$ km s^{-1}. Filled circles, open circles, and crosses depict $v \sin i$ measurements from the sources of Valenti & Fischer[76], H07, and G00, respectively.

along the main sequence[89,90]. All of those effects could contribute to the scatter seen in Fig. 12. Thus it becomes useful to consider plots of log R'_{HK} *versus* $v \sin i$ for stars within restricted ranges of $(B - V)$.

Dwarfs with colours in the range $(B - V) = 0^{m}\cdot60–0^{m}\cdot69$ are shown in Fig. 13. Among stars with an activity level of log $R'_{HK} > -4\cdot8$ there is a reasonable correlation between Ca emission strength and rotation speed. The great majority of low-activity dwarfs with log $R'_{HK} < -4\cdot8$ have projected rotation speeds of less than 5 km s^{-1}, and there is no obvious correlation between emission and $v \sin i$ among such stars. Thus the data show evidence of an activity–rotation correlation among the higher-activity stars in the diagram, but not the low-activity stars. One of the reasons for the latter trend in Fig. 13 is likely to be that among slowly-rotating stars small differences in rotation speed, say from 2 to 4 km s^{-1}, are comparable to the observational uncertainties, and therefore these stars merge together in Fig. 13. However, such stars will have long rotation periods that can differ by a factor of two and be accompanied by differences in activity level. Thus among slowly-rotating stars, it is preferable to have measurements of rotation period rather than rotation speed with which to search for activity–rotation correlations.

The data in Fig. 13 can be compared with a power-law relationship between R'_{HK} and the stellar rotation period P_{rot}. If the emission varies as $R'_{HK} \propto P_{rot}^{-\alpha}$, with α being a constant, and all stars are assumed to have the same inclination angle i, then this power-law can be rewritten as

$$\log R'_{HK} = \beta + \alpha \log(v \sin i), \qquad (1)$$

where β is a constant. As $v \sin i$ becomes small equation (1) will tend to a steeply-sloped curve in Fig. 13, which is qualitatively consistent with the
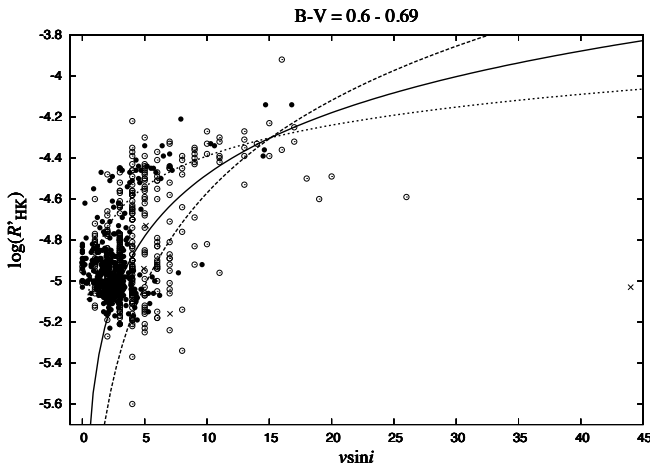
FIG. 13

The emission index log R'_{HK} *versus* projected rotation speed $v \sin i$ for dwarfs in the $(B - V)$ colour range $0^{m}\cdot60–0^{m}\cdot69$. The symbols depict the various catalogues from which the $v \sin i$ data were taken, as in Fig. 11. The dotted, solid, and dashed curves depict equation (1) for values of α = 0·5, 1·0, and 1·5, respectively, normalized so that all curves pass through the same point at $v \sin i = 15$ km s^{-1} and log $R'_{HK} = -4\cdot3$.

observed trend. Curves depicting equation (1) for three values of α (0·5, 1·0, 1·5) have been included in Fig. 13 as dotted, solid, and dashed lines, respectively, all arbitrarily chosen to intersect at $(v \sin i, \log R'_{HK}) = (15$ km s^{-1}, $-4\cdot3)$. The locus for $\alpha = 0\cdot5$ comes closest to matching the data for the more active stars. It does not, however, match well the data for the less-active dwarfs with $\log R'_{HK} < -4\cdot8$.

In a plot (not shown here) of $\log R'_{HK}$ *versus* $\log(v \sin i)$ for the stars in Fig. 13 there is essentially no correlation between emission strength and rotation speed at activity levels of $\log R'_{HK} < -4\cdot8$. However, among those stars with stronger emission there is a roughly linear trend, for which a least-squares fit gives a line of slope $\alpha = 0\cdot4$. Among the more active G dwarfs R'_{HK} thus seems to scale roughly as $v^{1/2}$.

Soderblom[83] found that the rotation speed of solar-type dwarfs varies with age t as $v \propto t^{-1/2}$, which combined with $\alpha \sim 0\cdot5$ suggests that $R'_{HK} \propto t^{-1/4}$. Trends of Ca II *HK* emission flux with age have been studied previously by Soderblom[21] and Pace & Pasquini[91] for solar-like stars in various open clusters and the field. Soderblom[21] found that $R'_{HK} \propto t^{-1/2}$. By contrast, Pace & Pasquini[91] concluded that while emission decreases notably with age for $t < 2$ Gyr, at later times "activity remains virtually constant for more than 3 Gyr" up to an age of 5 Gyr. A power-law of $R'_{HK} \propto t^{-1/4}$ represents a more gradual decrease of activity with age than the result found by Soderblom[21], but is perhaps better in keeping with the conclusions of Pace & Pasquini[91].

Alternatively, the $R'_{HK} \propto t^{-1/2}$ relationship of Soderblom[21] would be recovered if $\alpha = 1$ for G dwarfs. That appears to be too steep a relation to match the higher-activity stars in Fig. 13. However, the Soderblom[21] relationship is partly based on a comparison between Hyades-age dwarfs and old-disc dwarfs, and indeed a value of $\alpha \sim 1$ better accounts for the relative location of stars with $\log R'_{HK} \sim -4\cdot3$ and $-5\cdot2$ in Fig. 13. Thus, the difference between $\alpha \sim 0\cdot5$ for higher-activity dwarfs and the results from Soderblom[21,83] may indicate the limitations of a power-law representation as given by equation (1), and that α may be different among stars of different activity levels. Such is evidently the case in Fig. 8 of Noyes *et al.*[20], wherein the Ca II *H+K* emission varies more strongly with Rossby number among the lower-activity dwarfs than among those more active than $\log R'_{HK} \sim -4\cdot6$.

The curves in Fig. 13 provide a convenient reference that can be used to contrast the emission behaviour of the solar-like dwarfs with those in other colour ranges. Presented in Fig. 14 is an analogous plot of $\log R'_{HK}$ *versus* $v \sin i$ for dwarfs in the $(B - V)$ colour range 0^m·40–0^m·49. With progress along the main sequence from solar-like dwarfs to hotter effective temperatures the stellar radius increases, while the convective turnover time decreases[20]. Thus, at a given $v \sin i$, dwarfs in Fig. 14 will have a larger Rossby number than stars in Fig. 13, and since Ca II *H* and *K* emission decreases with increasing Rossby number, the stars in Fig. 14 would be expected to fall below and to the right of the curve(s) appropriate to solar-like dwarfs. That appears to be consistent with the observations. Dwarfs cooler than the Sun, in the colour range 0^m·70 $\leq (B - V)$ $\leq$ 0^m·79, are shown in Fig. 15. Many stars now fall above the curve for $\alpha = 0\cdot5$, which is consistent with them having smaller Rossby numbers than dwarfs of near-solar colour. Thus, although precise Rossby numbers cannot be calculated from $v \sin i$ values, the comparisons between Figs. 13–15 seem qualitatively consistent with that physical parameter being a determinant of chromospheric Ca II *H* and *K* emission for dwarf stars.
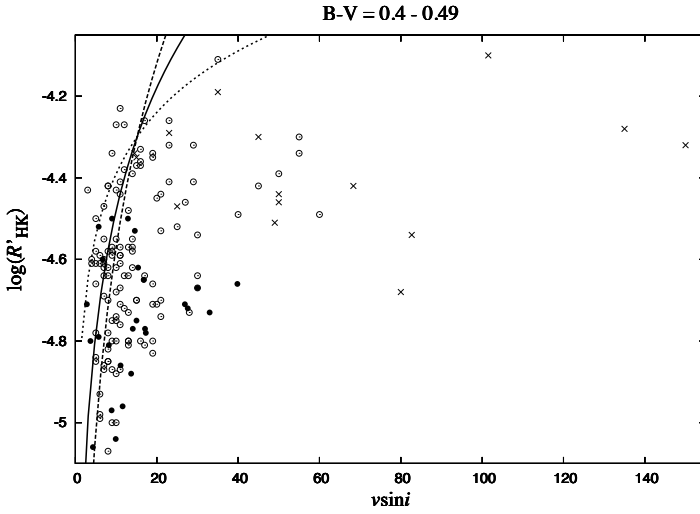
B-V = 0.4 - 0.49

The emission index log R'_{HK} *versus* projected rotation speed $v\sin i$ for dwarfs with $0^{m}\cdot40 \lesssim (B-V) \lesssim 0^{m}\cdot49$. The symbol conventions are the same as for Fig. 11, and the curves corresponding to equation (1) are the same as in Fig. 13.

B-V = 0.7 - 0.79

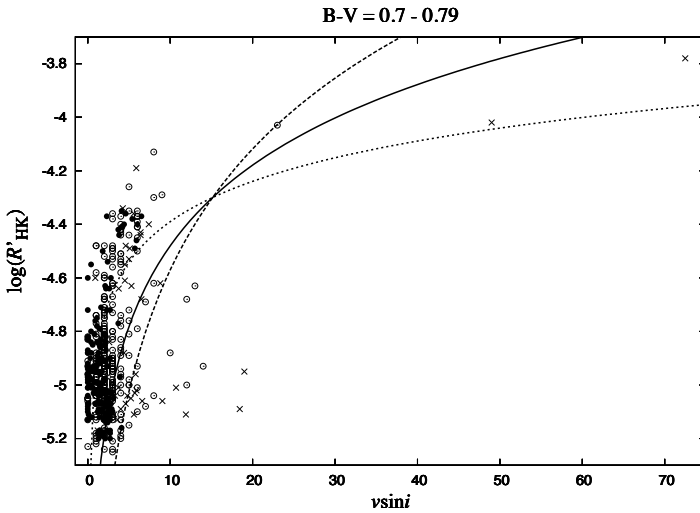The emission index log R'_{HK} *versus* projected rotation speed $v\sin i$ for dwarfs with $0^{m}\cdot70 \lesssim (B-V) \lesssim 0^{m}\cdot79$. Symbols are the same as for Fig. 11, and curves corresponding to equation (1) are the same as in Fig. 13.

References

(1) O. C. Wilson, *ApJ*, **226**, 379, 1978.
(2) A. H. Vaughan, G. W. Preston & O. C. Wilson, *PASP*, **90**, 267, 1978.
(3) A. H. Vaughan & G. W. Preston, *PASP*, **92**, 385, 1980.
(4) F. Middelkoop, A. H. Vaughan & G. W. Preston, *A&A*, **96**, 401, 1981.
(5) A. H. Vaughan *et al.*, *ApJ*, **250**, 276, 1981.
(6) A. H. Vaughan, in J. O. Stenflo (ed.), *Solar and Stellar Magnetic Fields: Origins and Coronal Effects*, (Reidel, Dordrecht), 1983, p. 113.
(7) S. L. Baliunas *et al.*, *ApJ*, **275**, 752, 1983.
(8) L. Hartmann *et al.*, *ApJ*, **276**, 254, 1984.
(9) S. L. Baliunas *et al.*, *ApJ*, **294**, 310, 1985.
(10) D. K. Duncan *et al.*, *ApJS*, **76**, 383, 1991.
(11) S. L. Baliunas *et al.*, *ApJ*, **438**, 269, 1995.
(12) J. C. Hall & G. W. Lockwood, *ApJ*, **438**, 404, 1995.
(13) T. J. Henry *et al.*, *AJ*, **111**, 439, 1996.
(14) R. O. Gray *et al.*, *AJ*, **126**, 2048, 2003.
(15) R. O. Gray *et al.*, *AJ*, **132**, 161, 2006.
(16) J. T. Wright *et al.*, *ApJS*, **152**, 261, 2004.
(17) J. S. Jenkins *et al.*, *MNRAS*, **372**, 163, 2006.
(18) J. S. Jenkins *et al.*, *A&A*, **485**, 571, 2008.
(19) F. Middelkoop, *A&A*, **107**, 31, 1982.
(20) R. W. Noyes *et al.*, *ApJ*, **279**, 763, 1984.
(21) D. R. Soderblom, *AJ*, **90**, 2103, 1985.
(22) D. R. Soderblom, D. K. Duncan & D. R. H. Johnson, *ApJ*, **375**, 722, 1991.
(23) D. R. Soderblom & M. Mayor, *AJ*, **105**, 226, 1993.
(24) H. J. Rocha-Pinto & W. J. Maciel, *MNRAS*, **298**, 332, 1998.
(25) R. P. Butler *et al.*, *ApJ*, **545**, 504, 2000.
(26) E. J. Gaidos, G. W. Henry & S. M. Henry, *AJ*, **120**, 1006, 2000.
(27) G. W. Henry *et al.*, *ApJ*, **529**, L41, 2000.
(28) G. W. Henry *et al.*, *ApJ*, **531**, 415, 2000.
(29) G. W. Marcy, R. P. Butler & S. S. Vogt, *ApJ*, **536**, L43, 2000.
(30) S. S. Vogt *et al.*, *ApJ*, **536**, 902, 2000.
(31) D. A. Fischer *et al.*, *ApJ*, **551**, 1107, 2001.
(32) D. Queloz *et al.*, *A&A*, **379**, 279, 2001.
(33) C. G. Tinney *et al.*, *ApJ*, **551**, 507, 2001.
(34) R. P. Butler *et al.*, *ApJ*, **578**, 565, 2002.
(35) G. W. Henry, R. A. Donahue & S. L. Baliunas, *ApJ*, **577**, L111, 2002.
(36) H. R. A. Jones *et al.*, *MNRAS*, **337**, 1170, 2002.
(37) G. W. Marcy *et al.*, *ApJ*, **581**, 1375, 2002.
(38) C. G. Tinney *et al.*, *MNRAS*, **332**, 759, 2002.
(39) S. S. Vogt *et al.*, *ApJ*, **568**, 352, 2002.
(40) R. P. Butler *et al.*, *ApJ*, **582**, 455, 2003.
(41) B. D. Carter *et al.*, *ApJ*, **593**, L43, 2003.
(42) D. A. Fischer *et al.*, *ApJ*, **586**, 1394, 2003.
(43) J. R. King *et al.*, *AJ*, **125**, 1980, 2003.
(44) M. Mayor *et al.*, *A&A*, **415**, 391, 2004.
(45) D. A. Fischer *et al.*, *ApJ*, **620**, 481, 2005.
(46) J. R. King & S. C. Schuler, *PASP*, **117**, 911, 2005.
(47) C. Saffe, M. Gómez & C. Chavero, *A&A*, **443**, 609, 2005.
(48) A. Eggenberger *et al.*, *A&A*, **447**, 1159, 2006.
(49) D. A. Fischer *et al.*, *ApJ*, **637**, 1094, 2006.
(50) J. Ge *et al.*, *ApJ*, **648**, 683, 2006.
(51) J. A. Johnson *et al.*, *ApJ*, **647**, 600, 2006.
(52) J. A. Johnson *et al.*, *ApJ*, **652**, 1724, 2006.
(53) G. Lo Curto *et al.*, *A&A*, **451**, 345, 2006.
(54) C. Melo *et al.*, *A&A*, **460**, 251, 2006.
(55) A. Sozzetti *et al.*, *A&A*, **449**, 417, 2006.

(56) S. Udry *et al.*, *A&A*, **447**, 361, 2006.
(57) J. C. Hall, G. W. Lockwood & B. A. Skiff, *AJ*, **133**, 862, 2007.
(58) G. W. Lockwood *et al.*, *ApJS*, **171**, 260, 2007.
(59) C. Melo *et al.*, *A&A*, **467**, 721, 2007.
(60) D. Naef *et al.*, *A&A*, **470**, 721, 2007.
(61) J. -C. Mermilliod, M. Mermilliod & B. Hauck, *A&AS*, **124**, 349, 1997.
(62) R. R. Radick *et al.*, *ApJS*, **118**, 239, 1998.
(63) G. W. Lockwood *et al.*, *ApJS*, **171**, 260, 2007.
(64) A. H. Vaughan, *PASP*, **92**, 392, 1980.
(65) D. K. Duncan *et al.*, *PASP*, **96**, 707, 1984.
(66) B. Nordström *et al.*, *A&A*, **418**, 989, 2004.
(67) L. Girardi *et al.*, *A&AS*, **141**, 371, 2000.
(68) B. Salasnich *et al.*, *A&A*, **361**, 1023, 2000.
(69) J. T. Wright, *AJ*, **128**, 1273, 2004.
(70) S. H. Saar, *BAAS*, **38**, 240, 2006.
(71) W. H. Soon *et al.*, *ApJ*, **416**, 787, 1993.
(72) L. W. Hartmann & R. W. Noyes, *ARA&A*, **25**, 271, 1987.
(73) E. Marilli, S. Catalano & C. Trigilio, *A&A*, **167**, 297, 1986.
(74) R. G. M. Rutten, *A&A*, **177**, 131, 1987.
(75) H. S. Yun & Y. D. Park, *J. Korean A. Soc.*, **21**, 79, 1988.
(76) J. A. Valenti & D. A. Fischer, *ApJS*, **159**, 141, 2005.
(77) J. Holmberg, B. Nordström & J. Andersen, *A&A*, **475**, 519, 2007.
(78) A. Baranne, M. Mayor & J.-L. Poncet, *Vistas in Astron.*, **23**, 279, 1979.
(79) D. W. Latham, in A. G. Davis Philip & D. W. Latham (eds.), *Stellar Radial Velocities*, (L. Davis Press, Schenectady), 1985, p. 21.
(80) R. Głębocki & A. Stawikowski, *Acta Astron.*, **50**, 509, 2000.
(81) R. P. Kraft, *ApJ*, **150**, 551, 1967.
(82) A. Skumanich, *ApJ*, **171**, 565, 1972.
(83) D. R. Soderblom, *ApJS*, **53**, 1, 1983.
(84) D. Cardini & A. Cassatella, *ApJ*, **666**, 393, 2007.
(85) H. A. Abt & J. H. Hunter Jr., *ApJ*, **136**, 381, 1962.
(86) D. F. Gray, *ApJ*, **261**, 259, 1982.
(87) J. R. Stauffer & L. W. Hartmann, *PASP*, **98**, 1233, 1986.
(88) K. Stępień, *A&A*, **292**, 191, 1994.
(89) R. L. Gilliland, *ApJ*, **299**, 286, 1985.
(90) S. M. Rucinski & D. A. VandenBerg, *PASP*, **98**, 669, 1986.
(91) G. Pace & L. Pasquini, *A&A*, **426**, 1021, 2004.

SPECTROSCOPIC BINARY ORBITS
FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 216: HD 144286, HD 149559, HD 152109, AND BD +23° 3009

By R. F. Griffin
Cambridge Observatories

   The first three of the four stars are all 9^m objects of *Henry Draper Catalogue* type K0, which came to attention in 'Clube Area 1'; the fourth star is a visual companion to another such object. Not so much as a single paper referring to any one of them is known to *Simbad*, but the three *HD* stars were observed by *Hipparcos*.

HD 144286 has a parallax and colour index that suggest a type of G8 V; it is in a near-circular orbit with a period a little short of a year. HD 149559 and the *BD* star are double-lined binaries having orbits whose plots look uncannily similar to one another, having almost identical longitudes of periastron and very similar eccentricities, though their periods (417 and 26 days) and velocity amplitudes (~ 18 and 46 km s^{-1}), respectively, differ substantially. Both are main-sequence systems; their respective spectral types are estimated at F6 + G1 and F6 + F7. HD 152109 is a giant star possessing *two* unseen companions: not only has it got a 516-day orbit of low eccentricity, but its γ-velocity has shown a linear decline that has accumulated to 6 km s^{-1} in seven years.

Introduction

It has been explained in previous papers in this series, most recently no. 176[1], that the 'Clube Selected Areas' programme involved the measurement of the radial velocities of sets of stars in 16 limited areas all at Galactic latitudes ±35° and longitudes spaced at intervals of 45°. The stars were selected from the *Henry Draper Catalogue*, all to be of type K0 and listed as having photo-visual magnitudes within half a magnitude of 9$^{\rm m}$. Twenty-five years ago the results of the principal work on the ten Areas accessible to the Cambridge telescope, almost all of it carried out with the original radial-velocity spectrometer[2] and giving radial velocities for 406 stars, were published[3]. Several correspondents then urged the completion of the work in the six remaining (southern-hemisphere) Areas, and that was done with the *Coravel* on the Danish 1·54-m telescope at La Silla, on which observing time was kindly granted by ESO; it was published comparatively recently[4,5] and gave velocities for 625 stars. The imbalance between the hemispheres was thereby reversed! — whereas the northern Areas had an average of only about 40 stars per Area, the southern ones had about 100. That was entirely due to the comparative richness of the *Henry Draper Catalogue* itself in the southern hemisphere*. With a view to restoring the imbalance, work on the northern Areas was resumed, the number of stars being augmented by increasing the sizes of the Areas while otherwise retaining the original selection criteria.

In the original publication[3] on the northern Areas, thirty spectroscopic binaries were identified. Orbits for all of them have by now been published, the last one (HD 134738) having been presented as recently as 2009 in Paper 208[6]. As a result of the renewed interest in the northern Areas, fresh spectroscopic binaries have naturally come to light, both among the stars that had already[3] been measured, and also among the 'new' ones. In the former category, orbits for three stars in Area 12 (Cetus/Taurus) were presented in Paper 165[7] of this series; among the altogether-fresh stars, the first orbits given were those of three

---

*Not only were the observing conditions better at Arequipa, where the southern-hemisphere objective-prism material for the *Henry Draper Catalogue* was obtained, than at Harvard where the northern-hemisphere plates were exposed, but the telescopes at both locations were provided with two prisms, with angles of 5° and 13°, offering a choice of dispersions differing by a factor of about three. It seems to have been left to the respective observers' discretion which prism to employ from night to night. Owing to perceived differences in the definition of the spectra, the observers at Harvard preferred the higher dispersion and those at Arequipa the lower one, with the end result that more than two-thirds of all the *HD* stars (actually 153 639 out of 225 300, 68·2%) are in the southern hemisphere!

TABLE I

Hipparcos/Tycho magnitudes, parallaxes, distance moduli, and absolute magnitudes

Star	V	$(B-V)$	π	$(m-M)$	M_V
	m	m	″·001	m	m
HD 144286	9·44	0·75	17·45 ± 1·30	3·79 ± 0·16	+5·65 ± 0·16
HD 149559	8·98	0·49	6·00 ± 0·94	6·11 ± 0·34	+2·87 ± 0·34
HD 152109	8·69	1·06	0·79 ± 0·88	≳ 8·4	≲ +0·3
BD +23° 3009	9·21	0·46	—	—	—

stars in Area 2 (Draco) and one in Area 10 (Pegasus) in Paper 176[1]. Here we present orbits for four more of the 'fresh' stars; they are all in Area 1 (nominally centred at $l = 45°$, $b = +35°$, whose approximate equatorial equivalents are RA = 16^h 50^m, $\delta = +25°$, mostly in Hercules but extending into parts of Corona Borealis and Serpens). Actually the easternmost of the stars treated here is not, strictly speaking, a Clube star at all but is a visual companion to one (HD 152327).

Nothing is known in advance of the present work about any of the stars apart from what appears in the *Henry Draper Catalogue* and, in the cases of the three *HD* stars, what was found by *Hipparcos/Tycho*. The photometric information in the latter obviously supersedes that in the *HD*, while it will be seen from the colour indices that the spectral classifications (all K0, by the definition of 'Clube' stars) in the latter are less probable than those that we can guess from photometry and parallaxes. In Table I, therefore, the *Hipparcos/Tycho* data, only, are presented — the deduced V and $(B-V)$ magnitudes, the parallaxes and corresponding distance moduli, and thence the absolute magnitudes of the systems. There is *no* bibliography retrieved by *Simbad* for any of the four stars. All of the radial velocities presented below have been acquired with the *Coravel*-type spectrometer at the coudé focus of the Cambridge 36-inch reflector. For the *HD* stars the observations began in 2003, for the *BD* star in 2004.

HD 144286

HD 144286 is in the constellation Corona Borealis, a little over 1° north-following the fifth-magnitude Ap star ι CrB. At 9^m·44 it is the faintest of the stars treated in this paper — fainter than the *BD* star which lacks an *HD* number. Having an absolute magnitude of about 5^m·6 and a $(B-V)$ of 0^m·77, HD 144286 is obviously a main-sequence star with a type close to G8. There are 45 radial velocities, set out in Table II; they lead to the orbit that is plotted in Fig. 1 and has elements as follows:

$$
\begin{aligned}
P &= 316\cdot0 \pm 0\cdot5 \text{ days} & (T)_5 &= \text{MJD } 54424 \pm 12 \\
\gamma &= -53\cdot12 \pm 0\cdot05 \text{ km s}^{-1} & T_0 &= \text{MJD } 54128\cdot0 \pm 0\cdot9 \\
K &= 3\cdot71 \pm 0\cdot08 \text{ km s}^{-1} & a_1 \sin i &= 16\cdot07 \pm 0\cdot34 \text{ Gm} \\
e &= 0\cdot092 \pm 0\cdot020 & f(m) &= 0\cdot00166 \pm 0\cdot00010 \, M_\odot \\
\omega &= 337 \pm 13 \text{ degrees} & \text{R.m.s. residual} &= 0\cdot32 \text{ km s}^{-1}
\end{aligned}
$$

The orbital eccentricity is quite small, but at more than four times its own standard deviation is definitely non-zero. The smallness of the eccentricity leads to a rather large uncertainty in the value of T, so the quantity T_0 (the epoch of the ascending node or time of maximum radial velocity) is given in addition.

TABLE II

Cambridge radial-velocity observations of HD 144286

Date (UT)		MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
2003 Aug.	19·89	52870·89	−49·5	0·085	−0·3
2004 Sept.	15·87	53263·87	−53·7	1·329	0·0
	18·81	266·81	−54·0	·338	−0·1
Oct.	7·78	285·78	−55·2	·398	−0·2
Nov.	13·73	322·73	−57·3	·515	−1·0
2005 Jan.	23·28	53393·28	−55·0	1·738	+0·1
Apr.	19·13	479·13	−49·0	2·010	+0·3
May	28·02	518·02	−49·8	·133	−0·1
June	11·00	532·00	−50·4	·177	+0·1
	26·99	547·99	−51·6	·228	−0·1
July	16·94	567·94	−53·1	·291	−0·2
Aug.	6·88	588·88	−54·2	·357	+0·1
	30·85	612·85	−55·5	·433	0·0
Sept.	7·82	620·82	−55·5	·458	+0·3
	17·87	630·87	−56·4	·490	−0·3
	23·82	636·82	−56·1	·509	+0·2
Oct.	20·77	663·77	−56·1	·594	+0·4
	31·74	674·74	−56·5	·629	−0·1
Nov.	12·72	686·72	−56·2	·667	−0·1
2006 Mar.	23·17	53817·17	−49·0	3·080	+0·2
Oct.	26·75	54034·75	−54·5	·768	0·0
Nov.	18·71	057·71	−52·7	·841	+0·1
2007 Apr.	4·14	54194·14	−51·8	4·273	+0·7
May	15·07	235·07	−54·7	·402	+0·4
July	6·99	287·99	−56·4	·570	+0·1
	18·95	299·95	−56·4	·608	+0·1
Aug.	26·94	338·94	−55·2	·731	0·0
Oct.	15·77	388·77	−52·2	·889	−0·6
	20·77	393·77	−50·7	·905	+0·5
	29·74	402·74	−50·5	·933	0·0
Nov.	12·73	416·73	−50·3	·977	−0·6
2008 July	4·04	54651·04	−55·5	5·719	−0·1
Aug.	1·89	679·89	−53·7	·810	−0·2
	10·87	688·87	−52·4	·838	+0·4
	25·88	703·88	−51·4	·886	+0·2
	30·84	708·84	−51·0	·902	+0·2
Sept.	18·82	727·82	−49·6	·962	+0·3
Oct.	5·77	744·77	−49·1	6·015	+0·1
	21·77	760·77	−48·8	·066	+0·3
2009 June	20·03	55002·03	−53·1	6·830	0·0
July	4·98	016·98	−52·2	·877	−0·3
Oct.	22·78	126·78	−51·8	7·224	−0·4
2010 Mar.	23·16	55278·16	−55·6	7·703	0·0
Aug.	30·88	438·88	−50·8	8·212	+0·4
Sept.	20·88	459·88	−53·2	·279	−0·6
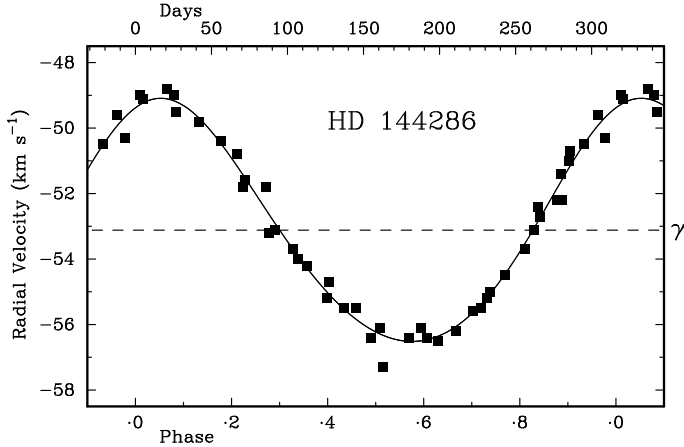
Fig. 1

The observed radial velocities of HD 144286 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All of the observations, in this and the other orbit plots, were obtained with the Cambridge *Coravel*.

HD 149559

HD 149559 is to be found about 2° preceding ζ Herculis. It is double-lined, as is illustrated by the radial-velocity trace reproduced as Fig. 2. There are altogether 42 radial velocities, listed in Table III; only one was made at a time when the system was absolutely single-lined, and was reduced as such, so there remain 41 pairs of velocities from which to deduce the orbit. The relative areas of the two dips (or depths, since neither of them is significantly broadened by axial rotation of the star) are found from the better-resolved traces to be 1 to 0·3, and that ratio has been imposed on the reductions of the more closely blended traces.

Fig. 2

Radial-velocity trace of HD 149559, obtained with the Cambridge *Coravel* on 2008 October 11.

TABLE III

Cambridge radial-velocity observations of HD 149559

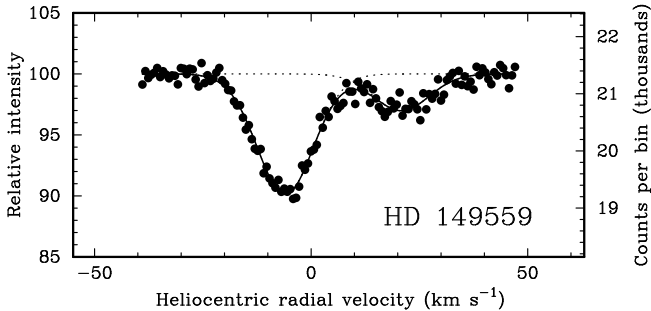| Date (UT)		MJD	Velocity Prim. km s⁻¹	Sec. km s⁻¹	Phase	(O−C) Prim. km s⁻¹	Sec. km s⁻¹
2003 Aug.	20·95	52871·95	+18·4	−3·4	0·570	+0·2	+0·3
	29·91	880·91	+17·7	−2·0	·591	+0·1	+1·0
Oct.	3·79*	915·79	+13·3	−0·3	·675	−0·9	−1·2
	14·79*	926·79	+12·9	−0·3	·701	+0·2	−2·9
Nov.	7·75	950·75	+8·0		·759	—	—
	24·71*	967·71	+3·8	+11·7	·800	−1·0	+0·1
2004 Jan.	17·27	53021·27	−10·8	+27·6	0·928	−0·3	−1·3
Feb.	9·23	044·23	−14·0	+34·0	·983	−0·1	+1·2
	26·22	061·22	−12·0	+31·5	1·024	0·0	+0·9
Apr.	7·14*	102·14	+1·9	+18·0	·122	+0·1	+3·0
May	22·04*	147·04	+13·2	+1·5	·230	0·0	−0·5
June	17·03	173·03	+17·0	−1·3	·292	+0·2	+0·8
July	6·99	192·99	+18·4	−3·7	·340	−0·1	+0·3
Aug.	7·97	224·97	+19·5	−4·2	·417	−0·2	+0·8
Sept.	1·88	249·88	+19·4	−4·6	·476	−0·3	+0·8
Nov.	13·75*	322·75	+14·7	−2·4	·651	−0·6	−2·0
2005 May	5·07	53495·07	−7·1	+25·1	2·065	−0·2	+0·3
	23·07*	513·07	−0·2	+20·1	·108	+0·1	+2·7
July	28·96*	579·96	+15·8	−0·8	·268	+0·2	0·0
Aug.	15·91	597·91	+17·3	−1·7	·311	−0·3	+1·2
Sept.	12·86	625·86	+19·4	−5·4	·378	+0·1	−0·5
Nov.	9·75	683·75	+19·3	−5·9	·517	0·0	−1·0
2006 Apr.	5·12	53830·12	−3·3	+20·6	2·868	−0·1	0·0
	12·14	837·14	−5·3	+23·3	·885	0·0	+0·3
May	11·06	866·06	−12·6	+31·3	·955	+0·3	−0·3
June	1·05	887·05	−13·3	+31·2	3·005	+0·1	−1·0
	22·01	908·01	−8·4	+25·8	·055	−0·1	−0·5
July	8·06	924·06	−2·7	+20·5	·094	−0·2	+0·7
2007 May	8·08*	54228·08	+3·1	+17·6	3·823	+0·8	+3·2
	19·07*	239·07	−0·8	+16·1	·849	0·0	−1·8
June	27·98	278·98	−12·3	+31·7	·945	−0·2	+0·9
July	8·05	289·05	−13·6	+33·3	·969	0·0	+0·8
Aug.	5·90	317·90	−10·2	+30·6	4·038	+0·3	+1·8
Oct.	15·82*	388·82	+11·7	−0·2	·208	+0·1	−4·1
2008 Aug.	2·92	54680·92	−8·4	+26·3	4·909	−0·1	−0·1
Oct.	11·80	750·80	−5·0	+21·9	5·077	+0·1	−0·8
2009 Apr.	29·11	54950·11	+18·7	−1·9	5·555	+0·1	+2·2
May	29·09*	980·09	+16·1	−0·2	·627	−0·3	+1·4
Sept.	18·85	55092·85	−6·7	+26·6	·897	+0·2	+1·8
2010 May	12·09	55328·09	+19·9	−4·5	6·462	+0·1	+1·0
June	3·07	350·07	+19·4	−3·6	·514	0·0	+1·4
	12·04	359·04	+19·1	−3·6	·536	+0·1	+1·0

*Rather close blends; velocities down-weighted by a factor of 5.

It is very noticeable in the diagram of the orbit (Fig. 3) that the results from such traces (the points that are nearest to the γ-velocity) are apt to exhibit much larger residuals than those where the blending is less serious or (near the nodes) absent. To obtain the most accurate orbital elements, it was necessary to give less weight to those measurements. To avoid an appearance of choosing subjectively or of undue opportunism in the choice of which results to down-weight, the ones so treated were chosen to be all those measured from traces where the primary's velocity was found to be within ±9 km s^{-1} of the γ-velocity. Twelve of the 41 SB2 measurements fall into that category, and needed to be down-weighted by a factor of five. Furthermore, the velocities of the secondary warranted a global weighting of only ½₀ in comparison with those of the primary. Thus the solution of the orbit relies mainly on the 29 measurements of the primary made at times when the components gave moderately or completely separate dips in the radial-velocity traces; the principal rôle of the measurements of the secondary is only to establish the velocity amplitude of that component. On that basis, the orbital elements were found as given below:

$$
\begin{array}{llll}
P & = & 416\cdot88 \pm 0\cdot13 \text{ days} & (T)_3 & = & \text{MJD } 53885\cdot0 \pm 0\cdot7 \\
\gamma & = & +7\cdot96 \pm 0\cdot04 \text{ km s}^{-1} & a_1 \sin i & = & 92\cdot3 \pm 0\cdot3 \text{ Gm} \\
K_1 & = & 16\cdot88 \pm 0\cdot05 \text{ km s}^{-1} & a_2 \sin i & = & 104\cdot6 \pm 1\cdot1 \text{ Gm} \\
K_2 & = & 19\cdot15 \pm 0\cdot20 \text{ km s}^{-1} & f(m_1) & = & 0\cdot1805 \pm 0\cdot0018 \ M_\odot \\
q & = & 1\cdot134 \pm 0\cdot013 \ (= m_1/m_2) & f(m_2) & = & 0\cdot263 \pm 0\cdot008 \ M_\odot \\
e & = & 0\cdot3020 \pm 0\cdot0034 & m_1 \sin^3 i & = & 0\cdot932 \pm 0\cdot023 \ M_\odot \\
\omega & = & 190\cdot8 \pm 0\cdot8 \text{ degrees} & m_2 \sin^3 i & = & 0\cdot822 \pm 0\cdot011 \ M_\odot
\end{array}
$$

$$\text{R.m.s. residual (unit weight)} = 0\cdot21 \text{ km s}^{-1}$$

The ratio of dip depths, expressed in terms of stellar magnitudes, is 1^m·3, and the use of the empirical factor 1·15 adopted by Griffin & Suchkov[8] for

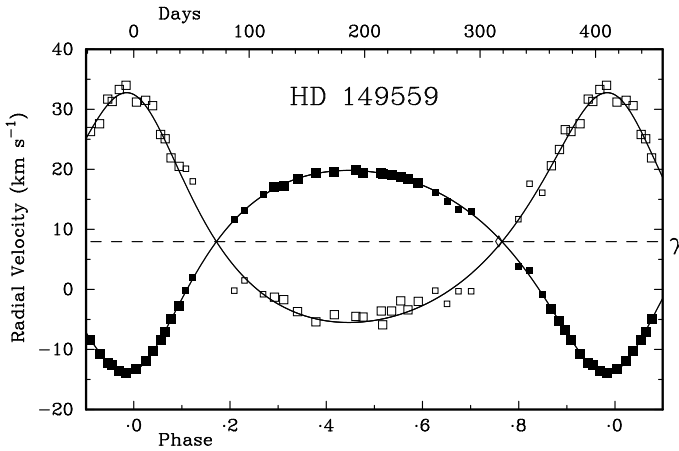Fig. 3

As Fig. 1, but for HD 149559. Measurements of the primary and secondary are distinguished by being plotted with filled and open symbols respectively. *Small* symbols plot the measurements whose accuracy was compromised by blending and that were given a weighting of only ⅕ in the solution of the orbit. The open diamond represents an observation that was necessarily reduced as single-lined.

converting a dip ratio to a *V*-magnitude difference for FG dwarfs would suggest that the components of HD 149559 should differ in *V* by nearly $1^m·5$. The rather accurately determined mass ratio, however, which is less easily gainsaid, points to a considerably smaller difference between the components. There is another slight conflict inasmuch as the parallax of the system makes it a little more luminous than would correspond to its colour index. Thus the photometric model offered in Table IV (below) has to be something of a compromise; it leans more towards the mass ratio than the *Δm*, and shows how the properties of a pair of main-sequence stars of types F6 and G1, which have a *ΔV* of $1^m·0$, combine to give an absolute magnitude that is about 1σ from the value that corresponds to the parallax and a colour index that is exactly the observed one. The factor $\sin^3 i$, by which the actual masses are multiplied in the parameters determined by the orbit, may be held to be about 0·78, with an uncertainty that can hardly be more than a very few per cent. Therefore $\sin i \sim \sqrt[3]{0·78}$, or 0·92, with an uncertainty that is probably only about 0·01, so $i \sim 67°$, within a degree or two.

TABLE IV

Photometric model (absolute magnitudes, colour index) for HD 149559

	Star	M_V m	(B–V) m	M_B m
Model	F6 V	3·6	0·45	4·05
	G1 V	4·6	0·60	5·20
	F6 V + G1 V	3·24	0·49	3·73
HD 149559 (observed)		2·87	0·49	

On one occasion (2003 November 7), as a result of mis-setting the telescope by one minute of time in right ascension, HD 149720 was inadvertently observed initially by mistake for HD 149559. It gave a velocity of +6·8 km s^{-1}. A (deliberate) confirmatory observation on 2010 October 6·78 gave +7·4 km s^{-1}.

HD 152109

HD 152109, about 2° following *η* Herculis in the sky, is clearly a giant star, since the parallax of less than one millisecond of arc (corresponding to a distance modulus of ten magnitudes) is smaller than its own standard error. The 1-σ lower limit to the distance modulus is about $8^m·4$, at which the absolute magnitude would be close to zero, while the corresponding upper limit is infinite and cannot usefully be discussed. On the assumption — it is nothing more — that the luminosity is no higher than that of a normal giant, the colour index would indicate a spectral type of K0 III.

The first radial-velocity observation was made in 2003; when the next, in late 2004, disagreed, the object was transferred to the spectroscopic-binary programme. Two years later, when the star was clearly beginning a second orbital cycle, it seemed troublesome that the velocities did not agree with those found the first time round but were offset negatively. It was found necessary to assume that there was an additional downward trend in the velocities as well as the obvious orbital motion. That trend has continued, in a remarkably linear fashion, to the present day (late 2010). A solution of the 56 available radial velocities (Table V), with the addition of a seventh 'orbital' element, to represent the trend, in the calculation, yields the result set out on page 26 below. To represent it graphically requires two diagrams (Figs. 4 and 5), the

TABLE V

Cambridge radial-velocity observations of HD 152109

Note: rounding can cause discrepancies of 0·1 km s⁻¹ among computed quantities

Date (UT)		MJD	Observed Velocity km s⁻¹	Phase	Computed velocity γ km s⁻¹	Orbital km s⁻¹	(O−C) km s⁻¹
2003 Aug.	29·93	52880·93	−12·8	0·667	−11·3	−1·2	−0·4
2004 Nov.	4·78	53313·78	−7·6	1·506	−12·3	+5·0	−0·3
	14·72	323·72	−7·7	·525	−12·3	+4·4	+0·2
2005 May	8·05	53498·05	−20·7	1·863	−12·8	−7·9	0·0
June	1·03	522·03	−20·9	·910	−12·8	−8·1	0·0
July	16·98	567·98	−18·7	·999	−12·9	−6·1	+0·4
Aug.	15·93	597·93	−16·4	2·057	−13·0	−3·5	+0·1
	30·86	612·86	−14·6	·086	−13·0	−1·9	+0·4
Sept.	12·88	625·88	−13·7	·111	−13·1	−0·5	−0·1
	25·83	638·83	−12·4	·136	−13·1	+0·8	−0·1
Oct.	20·77	663·77	−9·9	·184	−13·2	+3·2	+0·1
Nov.	9·77	683·77	−8·9	·223	−13·2	+4·7	−0·4
	29·71	703·71	−7·2	·262	−13·3	+5·9	+0·1
Dec.	8·71	712·71	−7·2	·279	−13·3	+6·3	−0·3
2006 Mar.	23·18	53817·18	−8·0	2·482	−13·5	+5·6	−0·1
Apr.	12·15	837·15	−9·3	·520	−13·6	+4·6	−0·3
	26·07	851·07	−10·2	·547	−13·6	+3·7	−0·2
May	11·07	866·07	−10·9	·576	−13·7	+2·6	+0·2
June	10·99	896·99	−13·6	·636	−13·7	+0·2	0·0
	23·03	909·03	−14·7	·659	−13·8	−0·8	−0·1
July	3·98	919·98	−15·3	·681	−13·8	−1·8	+0·3
	15·05	931·05	−16·2	·702	−13·8	−2·7	+0·3
	24·93	940·93	−17·2	·721	−13·8	−3·5	+0·2
Aug.	7·94	954·94	−18·3	·748	−13·9	−4·6	+0·2
	28·90	975·90	−19·8	·789	−13·9	−6·1	+0·3
Sept.	10·87	988·87	−20·5	·814	−14·0	−6·9	+0·4
Nov.	1·76	54040·76	−22·2	·915	−14·1	−8·1	0·0
	6·80	045·80	−22·1	·924	−14·1	−8·0	0·0
	18·75	057·75	−21·8	·948	−14·1	−7·6	0·0
	29·72	068·72	−21·8	·969	−14·2	−7·1	−0·5
Dec.	2·70	071·70	−21·0	·975	−14·2	−7·0	+0·1
	16·71	085·71	−20·6	3·002	−14·2	−6·0	−0·4
2007 Apr.	2·15	54192·15	−10·3	3·208	−14·5	+4·2	0·0
May	23·09	243·09	−7·7	·307	−14·6	+6·8	+0·1
June	21·00	272·00	−7·2	·363	−14·7	+7·2	+0·3
July	26·95	307·95	−7·8	·432	−14·7	+6·6	+0·3
Aug.	30·93	342·93	−9·6	·500	−14·8	+5·1	+0·1
Oct.	29·77	402·77	−14·1	·616	−15·0	+1·0	−0·1
2008 Mar.	5·23	54530·23	−23·0	3·863	−15·3	−7·9	+0·2
June	26·03	643·03	−17·5	4·082	−15·6	−2·1	+0·2
July	24·91	671·91	−14·7	·138	−15·6	+0·9	0·0
Aug.	10·92	688·92	−13·1	·171	−15·7	+2·5	0·0
Sept.	18·86	727·86	−10·4	·246	−15·8	+5·5	−0·1
Nov.	7·74	777·74	−9·0	·343	−15·9	+7·2	−0·3
Dec.	6·70	806·70	−8·9	·399	−16·0	+7·0	0·0
2009 Mar.	27·19	54917·19	−15·4	4·613	−16·2	+1·2	−0·3
May	29·10	980·10	−20·8	·735	−16·4	−4·1	−0·3
June	17·02	999·02	−22·0	·771	−16·4	−5·5	−0·1
July	20·00	55032·00	−24·2	·835	−16·5	−7·4	−0·3
Aug.	15·03	058·03	−24·9	·886	−16·6	−8·1	−0·2

Table V (*concluded*)

Date (UT)		MJD	Observed Velocity km s⁻¹	Phase	Computed velocity γ km s⁻¹	Orbital km s⁻¹	(O − C) km s⁻¹
2009 Oct.	22·78	55126·78	−22·1	5·019	−16·7	−5·3	−0·1
Nov.	3·76	138·76	−21·1	·042	−16·8	−4·2	−0·1
	17·73	152·73	−19·4	·069	−16·8	−2·8	+0·2
2010 May	17·08	55333·08	−10·2	5·419	−17·2	+6·8	+0·2
June	3·08	350·08	−10·7	·452	−17·3	+6·3	+0·3
Aug.	15·92	423·92	−15·5	·595	−17·5	+1·9	+0·1

first to demonstrate the variation of the orbit's γ-velocity with time and the second a more 'normal' one to portray the orbital velocity with respect to the γ-velocity as a function of phase, but differing from the usual orbit picture by the γ-velocity being at the zero velocity on the ordinate. It is the summation of the velocities from the two graphs that represents the actual velocity of the star at any given time. In effect, the value plotted in each graph is the observed velocity *less* the computed contribution from the other source of variation. It follows that a given observation exhibits the same residual in each of the two graphs. (We would not be so deceitful as to *share* the residual between the two variations and thereby cosmetically to halve it!)

$$P = 516 \cdot 1 \pm 0 \cdot 4 \text{ days} \qquad (T)_3 = \text{MJD } 54085 \pm 6$$
$$\gamma = -13 \cdot 99^\star \pm 0 \cdot 03 \text{ km s}^{-1} \qquad a_1 \sin i = 54 \cdot 2 \pm 0 \cdot 3 \text{ Gm}$$
$$K = 7 \cdot 67 \pm 0 \cdot 05 \text{ km s}^{-1} \qquad f(m) = 0 \cdot 0239 \pm 0 \cdot 0004 \, M_\odot$$
$$e = 0 \cdot 084 \pm 0 \cdot 006$$
$$\omega = 223 \pm 4 \text{ degrees} \qquad \text{R.m.s. residual (wt. 1)} = 0 \cdot 22 \text{ km s}^{-1}$$

★At MJD 54000. The γ-velocity declines by $2 \cdot 44 \pm 0 \cdot 05$ km s⁻¹ per 1000 days, so at (MJD) time t, $\gamma = -13 \cdot 99 - 2 \cdot 44(t - 54000)/1000$ km s⁻¹

This is only the third time in this series of papers that a trend such as is plotted in Fig. 4 has been formally computed by the program that fits it as a seventh unknown. The first occasion was in Paper 178, relating to HD 112445. That paper[9] recalls previous instances[10] in which trends were observed, but in those cases they were fitted 'by eye'; it was honest enough to admit that the computed trend differed not at all from what could equally well have been derived subjectively. The one advantage that was seen as accruing from the use of the computer (apart from the psychological one afforded to the author!) was to quantify the precision with which the trend was determined; that is seen in the present instance to be very high — the trend is established to about fifty times its standard error. It is still, of course, only a linear approximation to a (probably small) portion of a Keplerian orbit, whose completion the writer cannot afford to await before presenting the facts about the relatively short-period variation. All the same, HD 152109 will be retained on the observing programme and measured occasionally, as indeed has been the case for the other stars (HR 965, HD 7426, HR 2879 B, HD 112445, HD 14415, HR 3112) that have shown trends in the past[9,10], in all of whose cases the trends have departed from linearity as more of the 'outer' orbital periods have elapsed.

No evidence has been seen of either of the companion objects that must be present in HD 152109, but that is perhaps not too surprising given that the primary is evidently a giant. They could well be lower-main-sequence stars, although the possibility that either or both are white dwarfs cannot be refuted.
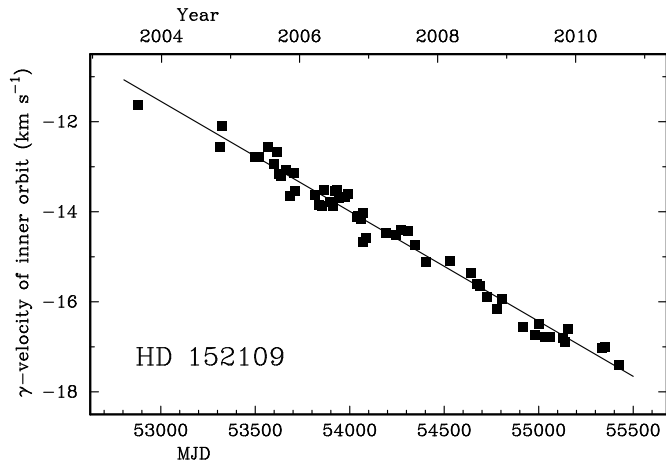
FIG. 4

The γ-velocity of HD 152109, plotted directly against time. The quantity plotted for each point is the observed velocity *minus* the computed contribution from the motion in the adopted 516-day orbit.
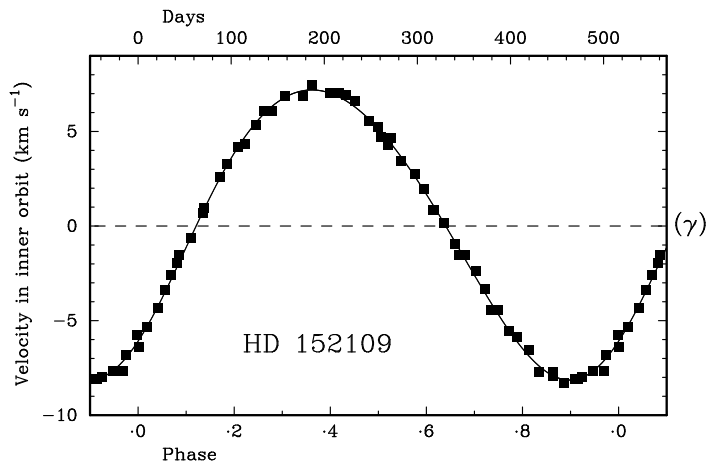
FIG. 5

Analogous to Fig. 1, but the ordinate shows the velocity with respect to the contemporaneous γ-velocity as defined by the straight line drawn through the points in Fig. 4.

The mass function of the inner orbit requires the closer companion to have a mass of at least 0·5 $M_\odot$ if the mass of the primary is taken to be 2 $M_\odot$, so if it is a main-sequence object it could be no later than M0. The presently unknown orbit of the outer companion, which already has a minimum amplitude of 3 km s^{-1}, promises to demand a mass at least as large for that object.

A fainter star (9^m·67) seen in the same field as HD 152109, at a relative position, roughly measured on an *Aladin* picture, 3′·93 distant in p.a. 300°, was observed on 2008 September 18·86 and 2010 October 6·78, with results of +21·2 and +21·5 km s^{-1}. The object is actually better known than HD 152109 itself, being an *Hipparcos* star as well as having the *BD* designation +39° 3048, and is also a Vyssotsky[11] dM star, very nearby in astronomical terms and having a large proper motion.

BD +23° 3009 ('HD 152327 B')

This *BD* star is about 3′ following HD 152327 and has been regarded by the writer as an optical companion to that star; it is about 1° south of 51 Herculis. Its radial velocity was first measured, in 2004, merely to assuage somewhat the observer's innate curiosity when he noticed another object in the field of one of the actual Clube stars, *viz*., HD 152327. The *BD* object is actually double-lined, but at that first observation it happened to be at a single-lined phase. A second observation was made in 2006 and was in major conflict with the first. On that occasion only one of the two 'dips' in the trace (it was actually that of the secondary star) was noticed initially, and then in the usual observing routine the range of the scan was promptly restricted to the vicinity of that dip, and the other one, being outside the reduced range, was missed. It was not until the third observation, when the velocity separation of the components was relatively small, that the double-lined nature of the radial-velocity trace was recognized. An example of a trace is shown as Fig. 6. The two dips are of almost equal areas and depths, and in some traces the identities of the primary and secondary cannot be distinguished, but on average there is found to be a difference of about 10% between them.

There are altogether 37 observations, listed in Table VI; one of them (as related above) is of the secondary only, and two are single-lined and cannot contribute to the solution of the orbit. Thus there are 34 useful measurements of the primary star and 35 of the secondary. One pair of velocities, stemming from an observation that was terminated by cloud well before the usual level of photon counts was reached, has been half-weighted. A curious feature of the measurements is that those of the primary are considerably more ragged than
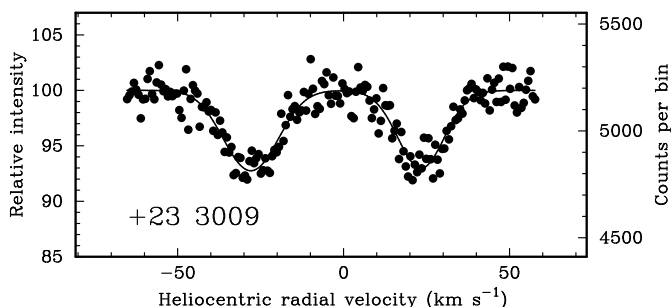

Fig. 6

Radial-velocity trace of BD +23° 3009, obtained with the Cambridge *Coravel* on 2008 July 24. The left-hand dip is that of the primary star.

TABLE VI

Cambridge radial-velocity observations of BD +23° 3009

Date (UT)		MJD	Velocity Prim. km s⁻¹	Velocity Sec. km s⁻¹	Phase	(O−C) Prim. km s⁻¹	(O−C) Sec. km s⁻¹
2004 Nov.	19·72	53328·72	−2·5		0·163	—	—
2006 July	16·00	53932·00	—	−27·9	23·484	—	+0·5
Sept.	10·90	988·90	+11·4	−16·4	25·683	−0·8	−0·1
Oct.	26·77	54034·77	+24·5	−29·1	27·456	0·0	−0·4
Nov.	1·77	040·77	+12·5	−15·1	·688	+0·9	+0·6
	2·78	041·78	+5·6	−9·4	·727	−1·0	+1·1
	3·77	042·77	−2·3		·766	—	—
	6·76	045·76	−30·0	+26·8	·881	−0·1	+0·2
	9·73	048·73	−59·6	+55·6	·996	−0·4	−0·8
	18·72	057·72	+22·5	−26·8	28·343	+0·1	−0·2
	20·72	059·72	+22·9:	−29·2:	·421	−1·5	−0·5
	23·72	062·72	+24·4	−26·8	·537	+1·7	+0·1
2007 Apr.	5·15	54195·15	+16·1	−19·4	33·656	+1·1	−0·3
	10·12	200·12	−20·3	+15·8	·848	−1·1	+0·1
	12·16	202·16	−46·2	+43·6	·927	+0·1	+0·3
	16·14	206·14	−31·4	+26·8	34·081	−1·5	+0·2
	30·11	220·11	+17·5	−22·4	·621	−0·5	−0·3
May	23·10	243·10	+24·1	−28·5	35·510	+0·5	−0·7
	31·04	251·04	−9·4	+6·9	·817	+1·2	0·0
July	7·02	288·02	+14·4	−18·3	37·246	0·0	+0·2
	8·03	289·03	+18·1	−22·4	·285	−0·4	+0·3
	26·96	307·96	−55·1	+53·8	38·017	+0·5	+1·1
Oct.	17·79	390·79	+11·9	−13·8	41·219	+1·4	+0·7
2008 July	21·95	54668·95	−58·6	+56·0	51·971	−0·3	+0·5
	23·98	670·98	−43·0	+40·2	52·050	+0·7	−0·4
	24·93	671·93	−27·1	+24·2	·087	+0·3	+0·1
Sept.	26·85	735·85	+22·2	−27·0	54·557	+0·4	−1·0
	27·81	736·81	+19·7	−24·8	·595	−0·1	−0·8
Oct.	5·80	744·80	−37·5	+34·1	·903	+0·3	−0·5
	8·79	747·79	−55·8	+52·5	55·019	−0·8	+0·4
2009 May	30·07	54981·07	−48·4	+45·3	64·037	+0·6	−0·8
Aug.	17·87	55060·87	−13·5	+8·9	67·122	+0·1	−1·1
	24·91	067·91	+23·1	−28·1	·394	−0·9	+0·2
2010 Apr.	17·14	55303·14	+23·8	−28·1	76·487	−0·3	+0·2
May	22·08	338·08	−16·5	+13·3	77·837	−0·4	+0·7
	23·06	339·06	−27·4	+24·1	·875	+0·5	−0·4
	24·06	340·06	−40·5	+37·9	·914	+1·1	−0·7

those of the secondary, by a factor of just about two in the variance. Such an *F* ratio between two sets of data each having some 30 degrees of freedom is significant at the level of about 2½%, so it is either a statistical fluke or it is trying to tell us that there is some real instability — which would need to be near 0·5 km s⁻¹ r.m.s. — in the primary's velocity. We are not in a position to choose between those possibilities, both of which seem a bit far-fetched, but we take the practical course of down-weighting the velocities of the primary by a factor of two in the solution of the orbit. The elements are given in the informal table below, and the orbit is plotted in Fig. 7. A comparison of that figure with Fig. 3 will impress the reader with their remarkable similarity, which arises from the
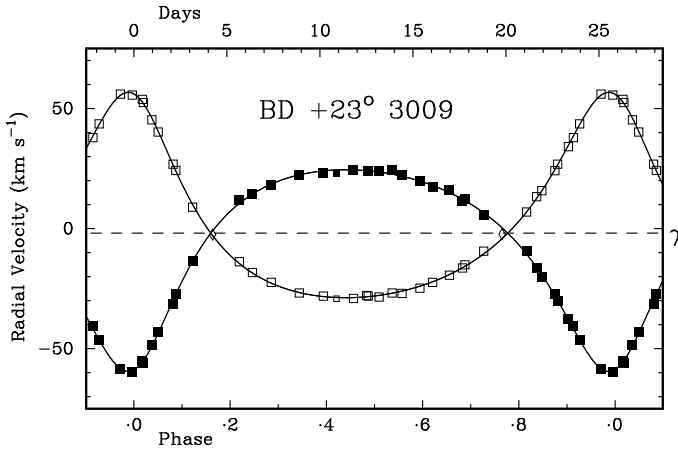
The observed radial velocities of BD +23° 3009 plotted as a function of phase, with the velocity curves corresponding to the adopted orbital elements drawn through them. The coding of the plotting symbols follows that of (the extraordinarily similar-looking) Fig. 3. The components of BD +23° 3009 are almost equal (Fig. 6), and their velocities do not seem to be particularly ragged where the blending is severe, so velocities derived from closely blended traces have not been down-weighted in this orbit as they have in the case of HD 149559 (Fig. 3).

very similar orbital eccentricities and almost identical longitudes of periastron. Although the periods and amplitudes of the orbits are quite different, the scale of the abscissae in such figures is always normalized to the orbital period, and of course the scale of the ordinates is so chosen as to make the best use of the area of the circumscribing box, so the scaling negates the differences in both those respects.

$$
\begin{array}{llll}
P & = & 25{\cdot}8690 \pm 0{\cdot}0005 \text{ days} & (T)_{45} & = & \text{MJD } 54488{\cdot}608 \pm 0{\cdot}027 \\
\gamma & = & -1{\cdot}90 \pm 0{\cdot}08 \text{ km s}^{-1} & a_1 \sin i & = & 13{\cdot}84 \pm 0{\cdot}07 \text{ Gm} \\
K_1 & = & 42{\cdot}01 \pm 0{\cdot}20 \text{ km s}^{-1} & a_2 \sin i & = & 14{\cdot}09 \pm 0{\cdot}05 \text{ Gm} \\
K_2 & = & 42{\cdot}76 \pm 0{\cdot}15 \text{ km s}^{-1} & f(m_1) & = & 0{\cdot}1581 \pm 0{\cdot}0024 \ M_\odot \\
q & = & 1{\cdot}018 \pm 0{\cdot}006 \ (= m_1/m_2) & f(m_2) & = & 0{\cdot}1668 \pm 0{\cdot}0018 \ M_\odot \\
e & = & 0{\cdot}3777 \pm 0{\cdot}0025 & m_1 \sin^3 i & = & 0{\cdot}655 \pm 0{\cdot}006 \ M_\odot \\
\omega & = & 190{\cdot}6 \pm 0{\cdot}5 \text{ degrees} & m_2 \sin^3 i & = & 0{\cdot}644 \pm 0{\cdot}008 \ M_\odot
\end{array}
$$

R.m.s. residual (unit weight) $= 0{\cdot}55$ km s^{-1}

For this system, alone among the stars treated in this paper, there is no parallax to inform us of the absolute magnitude; none is needed, however, because there can be no doubt that we are dealing here with a main-sequence pair, otherwise it could scarcely have an eccentric orbit with period of only 26 days, especially with components showing negligible rotational velocities. The difference of about 10% in the dip areas translates to a little over 0ᵐ·1 in *V* magnitude or less than one sub-type in spectral type, and the mass ratio this time is in perfect agreement. Then the (*B* − *V*) colour index of 0ᵐ·46 leads to an expectation that the types of the stars must be near to F6 and F7 and to a

combined absolute magnitude of about $2^{\text{m}}{\cdot}9$. Thus we can deduce for ourselves that the distance modulus is about $6^{\text{m}}{\cdot}3$, corresponding to a parallax of about $5{\cdot}5$ milliseconds of arc. The stars can be expected to have masses that are about $1{\cdot}9$ times the values of $m_{1,2}\sin^3 i$ given above from the orbit, so we can infer that $\sin i \sim 1/\sqrt[3]{1{\cdot}9}$, or just over $0{\cdot}8$, so $i \sim 54°$.

References

(1) R. F. Griffin, *The Observatory*, **124**, 190, 2004 (Paper 176).
(2) R. F. Griffin, *ApJ*, **148**, 465, 1967.
(3) R. F. Griffin, *MNRAS*, **219**, 95, 1986.
(4) R. F. Griffin & A. P. Cornell, *MNRAS*, **371**, 1140, 2006.
(5) R. F. Griffin, *MNRAS*, **371**, 1159, 2006.
(6) R. F. Griffin, *The Observatory*, **129**, 264, 2009 (Paper 208).
(7) R. F. Griffin, *The Observatory*, **122**, 210, 2002 (Paper 165).
(8) R. F. Griffin & A. A. Suchkov, *ApJS*, **147**, 103, 2003.
(9) R. F. Griffin, *The Observatory*, **124**, 371, 2004 (Paper 178).
(10) R. F. Griffin, *The Observatory*, **108**, 90, 1988; **109**, 180, 1989; **114**, 268, 1994; **126**, 265, 2006 (Papers 80, 88, 119, & 189).
(11) A. N. Vyssotsky & B. A. Mateer, *ApJ*, **116**, 117, 1952.

CORRESPONDENCE

To the Editors of 'The Observatory'

A Meteorite Crater on Mt. Ararat?

In 2004 August, while climbing Mt. Ararat, we came across a well-outlined crater on its western slope, and the purpose of this letter is to raise awareness of this interesting feature. Ararat is best known from the *Bible* as the mountain on which Noah's Ark came to rest, and it has attracted many expeditions to search for the Ark, including, *e.g.*, one with participation of the lunar astronaut James Irwin. Ararat is an isolated volcano of 5156 m absolute altitude (above sea level) and of 4300 m relative altitude from the valley bottom, of 130 km circumference, with over 30 glaciers. The first recorded summit ascent was by the 1829 expedition of Parrot[1] of Dorpat University (now Tartu, Estonia).

We had only a brief opportunity to examine the crater, as our inspection and taking of a photo was disturbed by our local guides: the western and northern slopes of Ararat are closed to foreigners*. As a result, the entire area remains practically unexplored; for example, we chanced upon medieval ruins, which later appeared to be[2] a 5th–6th-Century Armenian basilica unknown to experts.

The crater, shown in Plate 1, is located at an altitude of around 2100 m, with geographic coordinates 39° 47′ 30″ N, 44° 14′ 40″ E. The diameter of the crater is about 60–70 m, and the depth is up to 15 m. The origin of the crater, either of a meteorite or volcanic origin, including the evaluation of its age, will need detailed study. It has well-outlined borders, more rocky on the western side, as seen in the photo. Although a volcanic origin of the crater cannot be excluded, it is definitely unique for the structure of the slopes of Ararat, and no report for such a phenomenon is found for Ararat or for more-thoroughly-surveyed nearby volcanoes and volcanic ranges (Aragatz, Geghama, *etc.*).

*Later, Turkish military authorities granted us exceptional permission to climb the mountain from the north.

To sum up, what is apparent is (*a*) the clearly-outlined round shape of the crater, (*b*) the clear cut of its rim, and that (*c*) it cannot be a result of a glacial erosion: as mountaineers, we recognize well structures formed by glaciation; also the surrounding soil was not of a moraine type. Moreover, 2100 m is far below the glacier line (now at about 3800 m), even taking into account possible climatic variations.

<div align="right">
Yours faithfully,
V. G. GURZADYAN
</div>

Yerevan Physics Institute and Yerevan State University
  Yerevan
    Armenia

    [gurzadyan@icra.it]

<div align="right">
and S. AARSETH
</div>

Institute of Astronomy
  Madingley Road
    Cambridge

    [sverre@ast.cam.ac.uk]

2010 September 20

<div align="center">

References

</div>

(1) F. Parrot, *Reise zum Ararat* (Berlin), 1834.
(2) V. G. Gurzadyan & V. Harutyunian, *Historical-Philological Journal of the Armenian Academy of Sciences*, **172**, 206, 2006.

<div align="center">

Photographing the Supernova Remnant CTB 1

</div>

The remarkable but very dim supernova remnant CTB 1 in Cassiopeia (see Plate 3) has a most interesting history. This particular SNR was catalogued by George Abell as a planetary nebula in his now-well-known catalogue, the eighty-fifth and penultimate entry (*i.e.*, Abell 85), but it was suggested by van den Bergh in 1960 and confirmed by Willis & Dickel in 1971 to be, in fact, not a planetary nebula but rather a galactic SNR whose emissions can be found in the optical[1], radio[2], and X-ray[3] portions of the spectrum. CTB 1 is approximately 3000 pc away and is about 30 pc in diameter, while it is estimated to be about 10 000 years old.

Note that at the 11-o'clock position, one is left with the impression that the 'urn' has a 'spout' and material is flowing out. Studies have confirmed this shell rupture, which extends up to 30′ to the east and past the main shell[1]. Also of interest is the stronger O III emission on the western section of the shell which I detected in my exposures and which coincides with scientific findings and

is believed[1] to represent "large-scale, incomplete shock cooling". Similarly, the greater contrast of the southern half of CTB 1 has been linked to the various dust clouds in the immediate area, also visible in my image. Finally, there is a neutron star in the immediate area on which I am working to determine its precise identification and location[4]. For a rich survey of academic literature related to CTB 1, consult ref. 5.

This particular SNR is one of the holy grails of amateur astronomy (see, *e.g.*, ref. 6) and is a most-difficult target for imagers as well owing to a very dim magnitude spread over a diameter of 35·2 arc-minutes, with the number of existing images of CTB 1 available on the internet being in single digits. In my pursuit of CTB 1, I employed perhaps the best 4-inch astrograph on the market (Takahashi FSQ 106/f5) as well as one of the most sensitive CCD cameras available to the amateur (SBIG ST-10XME, QE > 85%), which provide a field of view measuring 96 × 65 arc-minutes, thus allowing for ideal framing of the SNR and its outflow to the northeast as well as the surrounding nebulosity, structure, and filaments. Baader narrow-band CCD imaging filters were used as well as SBIG/Custom Scientific LRGB filters.

Six evenings in early September were dedicated to CTB 1 with two complete evenings for Hα, one complete evening for each of S II and O III, and one further evening for the LRGB portion so as to get the background sky and proper star colours for G2 V calibration. (The sixth evening was dedicated to re-shooting replacement exposures required because of planes and satellites.) More specifically, the narrow-band portion involved 50 × 30-min. exposures at −17·5° C whereas the LRGB portion was based on 40 × 3-min. and 30 × 6-min. exposures (also at −17·5° C), thus representing a total of 30 hours' data. (These totals do not include eight 30-min. integrations which were lost owing to planes or satellites and which can be attributed to the length of the 30-min. exposures.) Also, I had fairly significant light gradients, especially for the narrow-band images, thanks to the lengthy duration of the individual integrations and which were acute (the O III being the most severely affected).

<div style="text-align: right">

Yours faithfully,
ANTHONY AYIOMAMITIS

</div>

Agapis 2
  Nea Palatia-Oropou 19015
    Greece

      [Anthony@perseus.gr]

2010 September 28

References

(1) R. A. Fesen *et al.*, *AJ*, **113**, 767, 1997.
(2) R. Dickel & A. G. Willis, *A&A*, **85**, 55, 1980.
(3) G. Pannuti & J. Rho, *Bull. AAS*, **36**, 5, 2004.
(4) J. Hailey & W. W. Craig, *ApJ*, **455**, L151, 1995.
(5) http://www.mrao.cam.ac.uk/surveys/snrs/snrs.G116·9+0·2.html
(6) http://www.astronomy-mall.com/Adventures.In.Deep.Space/ctb1.htm

REVIEWS

The Life of Stars: The Controversial Inception and Emergence of the Theory of Stellar Structure, by G. Shaviv (Springer, Heidelberg), 2009. Pp. 504, 24 × 16 cm. Price £89·99/$129/€100 (hardbound; ISBN 978 3 642 02087 2).

"History is about chaps", to mis-quote the well-known clerihew*, and it is as true of the history of science as of any other history. To understand in detail how a subject area developed, one has to understand the historical context in which the scientists lived, and learn about their past experiences and accumulated prejudices. Only then can one fairly judge whether a particular person has made a brilliant breakthrough — or alternatively made a completely avoidable error.

Starting from this point of view, it is clear why Giora Shaviv's book on the development of the theory of stellar structure is so long and so detailed. If you are looking for a succinct overview of the main lines of development, you will need to look elsewhere. However, if you want to delve into the minutiae, and follow all the wrong turnings, then read on — this book may be for you. Beware of misprints, however — for example, in the Preface he refers to the discovery of quantum theory "during the first half of the *nineteenth* century" (my italics), on p. *vi* he spells Bohdan Paczynski's name incorrectly, and on p. 58 he introduces "Anjar" Hertzsprung, a spelling I have seen nowhere else (this leads to Hertzsprung appearing twice in the index, once with initial A. and once with initial E.). He also mis-defines β on p. 127 as the ratio of gas pressure to radiation pressure (the denominator should be total pressure), and on p. 150 gives Eddington's absorption coefficient as being in units of g/cm^3 (admittedly Eddington didn't help by simply saying his values are in c.g.s. units).

The first three chapters set the scene and provide the background against which Eddington wrote his seminal book *The Internal Constitution of the Stars*. The long first chapter addresses the controversy over the age of the Earth, with many digressions into Darwinian evolution, attempts to measure the cooling rate of the Earth, and some basic physics. Although much of this is interesting, I felt that it was perhaps over-long for its direct relevance to the development of ideas about stars. It also suffers (as does the rest of the book) from providing so much detail that it is sometimes hard to see the main argument. Chapter 2 switches to observations, with a discussion of stellar spectral classification and of interpretations of the Hertzsprung–Russell diagram in terms of stellar evolution. Chapter 3 returns to the Earth, discussing radioactivity as an energy source, and detailing the development of ideas about the atom and the discovery of quantum theory.

In Chapter 4 Shaviv finally turns to the structure of stars and again follows the twists and turns of the arguments: how important is radiation pressure? What is the mean mass of a particle? What are the absorption coefficients? What is the stellar energy source? It is remarkable that Eddington was able to make significant progress, and to obtain a theoretical mass–luminosity relation in acceptable agreement with observation, without really knowing the answer to any of these questions, and despite some of his guessed answers being wrong (in particular, the chemical composition of stars). One major error was to over-estimate (by a factor of a million) the rate of mixing inside stars, a result that dramatically affects the evolution of stars, and would prevent the formation of giant stars if true; this particular issue was not resolved until 1950, six years after

---

*"The art of Biography / Is different from Geography, / Geography is about maps, / But Biography is about chaps." (E. C. Bentley)

Eddington's death. In his well-known controversy with Jeans, Eddington was largely right, although he was entirely wrong in his criticism of Chandrasekhar's model of white-dwarf stars.

The next four chapters follow the later development of theory and observation, covering such topics as the application of Fermi–Dirac statistics to explain white-dwarf stars, ideas about supernovae, neutron stars, and black holes, the solution to the stellar energy problem and the development of nuclear astrophysics, and finally the evolution of both low-mass and high-mass stars. The final chapter concentrates on the Sun, taking solar neutrinos as a theme and touching on helioseismology.

For historians of science, Shaviv has done a considerable service by searching out many obscure or forgotten papers amongst the important and well-known ones, and he does give references to almost everything. He adds quite extensive footnotes as well when he wants to expand on a point in the text, or to give some of the background needed by a non-scientist. However, for the average worker in the field of stellar structure (and perhaps even more for other astronomers) I feel that a rather briefer and more tightly-argued version, tracing the main developments, might have been of more appeal. Shaviv's style is rather discursive, and involves some repetition as he explores a topic from several angles. He also goes into details about basic physics, which suggest that he is aiming for a wider readership than astronomers. I shall be glad to have read the book, but sadly it is not ideal as a reference book because the only index is one of people's names. The lack of any index of topics is a major omission, only partially compensated for by the use of relatively short sections and a very detailed contents list. Do I recommend this book? Yes, but with reservations. — ROBERT CONNON SMITH.

Extreme Environment Astrophysics, by U. Kolb (Cambridge University Press), 2010. Pp. 287, 25 × 18 cm. Price £75/$130 (hardbound; ISBN 978 0 521 19344 3), £35/$60 (paperback; ISBN 978 0 521 18785 5).

This book is one of a number written by Open University academics and published by CUP. Having used a previous volume, *An Introduction to the Solar System* by Neil McBride & Iain Gilmore, to teach planetary astronomy, I was expecting a high standard and was not disappointed. It should perhaps have been entitled "An Introduction to Extreme Environment Astrophysics". This is primarily an undergraduate textbook, although it would also provide a quick introduction for a graduate student new to the subject, but they would need soon to move on to more-demanding texts.

Explaining extreme astrophysics to an undergraduate without extreme mathematics, or total confusion, is a challenge for any author. Kolb has managed to produce a textbook with enough detail for a solid introduction presented in a clear and thoughtful style combined with a wonderful set of figures.

Accretion is of course the key phenomenon underlying many of the most extreme objects in the Universe, so it is no surprise that the bulk of the book is taken up with that topic. Starting with a discussion of the basics of energy extraction, Kolb goes on to discuss binary stars, discs, and outbursts. That's a good ploy as such systems are far better studied than their larger cousins, the active galaxies. The book includes many example questions (with answers), which provide a good test of understanding.

The last three chapters are primarily by co-authors Robin Barnard and Hara Papathanassiou, but maintain the clear style. These provide an overview of radiation processes in the relativistic régime and the properties of outflows and

gamma-ray bursts. As elsewhere in the book real observational data are used to demonstrate the physics and numerous suggestions are provided for further reading. — Paul O'Brien.

High Energy Phenomena in Massive Stars (ASP Conference Series, Vol. 422), edited by J. Martí, P. L. Luque-Escamilla & J. A. Combi (Astronomical Society of the Pacific, San Francisco), 2010. Pp. 306, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 724 7).

These are the Proceedings of an international meeting held at Jaén in 2009 February to review studies of massive stars with the new generation of γ-ray satellites and ground-based imaging Cherenkov telescopes. This is a great time for high-energy astrophysics. *AGILE* and *Fermi* (*GLAST*) have been observing for over two years now, and the first full catalogue of *Fermi LAT* sources is now (2010) publicly available. Early results from *AGILE* are reported by Giulani *et al.* in the last paper in this volume. The 3rd-generation imaging atmospheric Cherenkov telescopes like *HESS*, *MAGIC,* and *VERITAS* have led to the discovery of about a hundred VHE ($E > 100$ GeV) γ-ray sources, many from the *HESS* collaboration's Galactic-Plane Survey. A significant fraction of the sources are identified with the usual suspects, such as supernova remnants and pulsar-wind nebulae, but the emphasis here is on massive stars, where interactions with dense O-star winds or Be-star discs are clearly important.

The Proceedings move systematically through different flavours of HMXRB, the high-mass micro-quasars (HMMQ), massive binaries harbouring pulsars, and colliding-wind binaries (CWB) without compact components. Properties and emission processes are discussed in several contributions, of which I (as a non-expert) found those by Bosch-Ramon and Dubus most enlightening. They, and many other contributors, discuss different facets of the well-studied γ-ray binaries LSI+61 303, LS 5039, and PSR B1259–63/SS 2883, which appear to be far from well understood. Dubus suggests that the difference between γ-ray binaries and X-ray binaries may not only be phenomenological (*e.g.*, the former are radio emitters, which is generally rare amongst HMXRB), but also have roots in the physical mechanisms at work. By comparison, the CWBs seem rather tame: η Carinae alone has been detected in γ rays, while only upper limits have been placed on the high-energy emission from some of the well-observed Wolf–Rayet CWBs showing non-thermal radio emission. Radio emission by CWBs is discussed and modelled in a number of contributions. Those by Pittard and Dougherty show how modelling has progressed in the last few years with the inclusion of more realistic physical processes, whereas that by Blomme shows that there are still problems in understanding the radio light-curve of the apparently simple system Cyg OB2 #8A. Massive star clusters are expected to be VHE sources on account of interactions of massive stellar winds, formation of superbubbles, and particle acceleration. Ohm *et al.* discuss identification of a number of these with *HESS* sources while Knödlseder *et al.* discuss γ-ray observations of 30 Doradus in the LMC with *Fermi*.

The concentration on a relatively small subject area — albeit with emission over 20 decades in frequency! — makes this a very satisfying book. Production is good with very few errors (*e.g.*, the caption for the figure on p. 129 is for a colour version, and the symbol marking MWC 148 in the figure on p. 131 is missing) and the editors have provided general, object, and author indices. They and the authors should be commended on the speed of publication. — P. M. Williams.

Galaxy Wars: Stellar Populations and Star Formation in Interacting Galaxies (ASP Conference Series, Vol. 423), edited by B. J. Smith, N. Bastian, S. J. U. Higdon & J. L. Higdon (Astronomical Society of the Pacific, San Francisco), 2010. Pp. 376, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 726 1).

This book contains the proceedings of a conference held on 2009 July 19–22 at East Tennessee State University on the subject of galaxy interactions. Although I didn't attend myself, I knew many people who went, and I've since heard that this was a very stimulating meeting. Thus, taking the time to have a thorough read of the proceedings was a very interesting exercise for me. In this review, besides giving a brief synopsis, I will also pick out a few personal highlights.

As mentioned in the conference summary, this was a very diverse meeting scientifically, resulting from the fact that the study of galaxy interactions stands happily at the crossroads between a number of interrelated fields (*e.g.*, galaxy evolution, stellar evolution, star-cluster dynamics, interstellar-gas dynamics, star formation). A good proportion of the first half of the conference was devoted to looking at individual interacting systems that are near enough to study in detail. The meeting then went on to examine some of the processes associated with interaction (gas flows in a clustered environment, gas stripping, formation of star clusters) and some of the observational/theoretical techniques used to probe them (star clusters, population synthesis, numerical modelling). The final sections of the conference were devoted to larger-scale surveys of pre-merger and merging galaxies done using a variety of wavelengths and techniques.

For me, particular points of interest include the early talks on ring galaxies (Higdon, Pellerin), both for their intrinsic beauty and their potential for giving specific insight into interaction-triggered star formation; the consensus that interactions are much more common than previously thought, and that systems may be continually 'harassed' by interactions and minor-mergers throughout their history (J. Gallagher, Keel, Nigra, Walker); and, since star clusters can be used to trace the evolution of stellar populations within mergers (and are being used this way more and more), the whole on-going debate on the nature of star-cluster formation and destruction (L. Smith, B. Smith, Chandar, Gieles, *et al.*).

The rate of incoming new data is, of course, ever increasing, and it is this, together with insightful modelling efforts, that has significantly deepened our understanding over the last few decades of galaxy interactions and their effect within the evolution of the Universe. However, it is clear from these proceedings that deeper understanding simply allows us to ask more fundamental questions, and it is to these that future attention will be turned. — MARK WESTMOQUETTE.

Galaxy Evolution: Emerging Insights and Future Challenges (ASP Conference Series, Vol. 419), edited by S. Jogee, I. Marinova, L. Hao & G. A. Blanc (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 426, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 718 6).

These conference proceedings have resulted from an international meeting of the same title held at the University of Texas, Austin, in 2008 November. In recent years we have seen remarkable strides being made in our understanding of the cosmological model that describes our Universe, with results from many different experiments like the *WMAP* satellite converging on a concordance ΛCDM cosmology with very precisely defined amounts of baryons, dark matter, and dark energy. Despite the fact that the dark components constitute

the majority of the energy density of our Universe, it is the 4% of baryons that make up the stars, gas, and dust contained in galaxies, that present the most significant challenge to ΛCDM. Many of the predictions of a hierarchical ΛCDM cosmology do not in fact match observations, and theoreticians and observers alike have been tackling these discrepancies both through increasingly sophisticated simulations as well as deeper, higher-resolution observations. The term *feedback* has emerged as somewhat of a buzzword in helping to explain the discrepancies and encompasses a whole host of astrophysical phenomena, many of which still remain poorly understood.

These proceedings provide an excellent summary of the advances that have been made as well as the challenges that remain in tackling discrepancies between ΛCDM and observations. The abstracts span a wide range of topics all the way from observations of the local Universe to the most distant galaxies, from modelling the formation of bulges and bars in individual galaxies to cosmological simulations that reproduce the observed large-scale structure of the Universe.

Many of the articles in the first part are concerned with the formation of galactic bulges and bars. The ΛCDM models for galaxy formation often fail to explain the absence of bulges in dwarf galaxies but as Governato points out, feedback from star formation can effectively remove gas from the centres of dwarf galaxies. However, Combes argues that bulge formation is extremely efficient in galaxies, and hunting for precursors of modern-day bulgeless systems still presents a significant challenge to ΛCDM. Generally, many of the papers seem to agree, however, that bulges, when observed, are built up through a combination of minor mergers, smooth accretion, and secular evolution rather than the major merger scenario predicted by ΛCDM. Secular evolution is mainly driven by galactic bars and significant numbers of barred galaxies are observed in the local Universe by Marinova *et al.*, while Barazza *et al.* show that the barred fraction decreases with redshift.

Regarding the merger histories of galaxies, the general consensus from the observers is that a purely merger-driven-formation history for galaxies is inconsistent with the observations. Shapiro *et al.* conclude that elliptical galaxies at redshift 2 must have been assembled through inflow of gas along filaments, while Jogee reaches similar conclusions for galaxies at lower redshifts by using the exquisite data sets provided by the *Hubble Space Telescope*. However, the fact that this topic still remains highly debated is evidenced by the article by Skelton, Bell & Somerville in which the authors argue that dry merging can explain the evolution of early-type galaxies and observations of their colour–magnitude relationship.

The subject of *feedback* is also comprehensively covered. Kravstov provides a nice summary of the well-known *missing satellites* problem and the different feedback mechanisms such as supernova winds and IGM heating that are commonly invoked to help solve it. Observations of outflowing gas in galaxies that effectively show feedback in action are presented by Dave, Tremonti *et al.*, and Willis, among others. The issue of AGN feedback is tackled by Alexander, for example, who highlights the strides made in observing obscured AGN activity using multi-wavelength data sets.

Finally, Juric & Ivezic make a pertinent point regarding the contribution that next-generation telescopes such as the *LSST* will make to our understanding of this very exciting field of research. These proceedings provide a nice summary of many of the current hot topics in galaxy-evolution research and would make

an excellent addition to the bookshelf of any graduate student hoping to gain more insight into the field. More experienced researchers too will benefit from the wealth of reference material contained within its pages. — MANDA BANERJI.

Gravity's Fatal Attraction, 2nd Edition, by M. Begelman & M. Rees (Cambridge University Press), 2010. Pp. 302, 24·5 × 18·5 cm. Price £60/$99 (hardbound; ISBN 978 0 521 88944 5), £19·99/$36·99 (paperback; ISBN 978 0 521 71793 9).

This is the second edition of a highly successful popular book that first appeared in 1995. Its theme is the astrophysics of black holes. As the authors remark in the Preface to the second edition, doubts about the existence of black holes that were still prominent in 1995 have now largely disappeared in the plethora of new observational material tending to support the idea of them as real entities. This has allowed the authors to rewrite several chapters, and add new ones on gamma-ray bursts and cosmic feedback. Most strikingly, most of the images in the book, either observational or from simulations, are updated and greatly improved, direct results of vastly enhanced instrumentation and computers, respectively.

Both authors have had long and distinguished careers working at the frontiers in these subjects, so the treatment is authoritative in areas of general current consensus, and stimulating in areas where there is none. The explanation of the physics underlying the astrophysics is remarkably succinct and clear. The style is brisk and engaging, with frequent use of everyday analogies. As a minor quibble, figurative terms are always enclosed in quotes (*e.g.*, "ears", "lobes", "movie" all appear on a single page chosen at random, sometimes more than once). This may result from over-solicitous editing. At all events it gets wearing with repetition, as though the reader cannot be trusted to spot that the term is not meant literally.

Far more importantly, the main function of this type of book is to inform and enthuse. The authors have an admirable record of success in these aims, and this book extends it still further. Among scientific subjects, astronomy benefits from an almost unique public popularity. One reason for this is the willingness of its practitioners to tell the story, as here. In the hard times that may be coming this is a priceless asset. — ANDREW KING.

Relativity, Gravitation and Cosmology, by R. J. A. Lambourne (Cambridge University Press), 2010. Pp. 312, 26 × 21 cm. Price £80/$130 (hardbound; ISBN 978 0 521 76119 2), £35/$60 (paperback; ISBN 978 0 521 13138 4).

I am a great admirer of Bob Lambourne's Open University textbooks, which are models of clarity. As a result, I was very interested to see how his approach applied to a subject which is generally rather challenging to undergraduate physics students. The result is a book which will not suit all students but can be recommended for its target readership. It follows previous practice of having handy boxed definitions of terms and chapter summaries, and as always, Professor Lambourne shows a keen appreciation of what is likely to be challenging for a student. Any book on relativity needs to make an early decision on which mathematical techniques to introduce (or assume). There is an overhead for the student in mastering the techniques, of course, but the methods can at the least streamline calculations, and in many cases add insight. This book assumes rather less mathematical competence than most, and tends

not to introduce new techniques. The simplest example is that the Einstein summation convention is not employed, as a result of which the equations sometime look rather cumbersome. The advantage of the approach, though, is that it may be more accessible to a body of students who are not so comfortable with mathematics. There is a price to pay, however: some of the exercises which the students are asked to do will take longer, and use much paper, as the mathematical tools (or in some cases, the hints of how to get answers without doing many calculations) are missing. In addition, some standard calculations are left out, such as the Solar System tests of General Relativity, and a number of key ingredients are introduced with an 'it can be shown' or similar. Personally I think this is a pity, but I understand that a judgement has been made on how much detail to go into. In a few places the direction wasn't easy to follow, but on the whole the book is clearly written and nicely illustrated with historical details.

In summary, this book is a very laudable effort to bring a difficult subject to students who would find the mathematical level of a more typical text too challenging. Students who are more comfortable mathematically might find some of the omissions frustrating and an impediment to full understanding, but there are many existing books to satisfy their needs. — ALAN HEAVENS.

Numerical Relativity: Solving Einstein's Equations on the Computer, by T. W. Baumgarte & S. L. Shapiro (Cambridge University Press), 2010. Pp. 698, 25 × 19 cm. Price £55/$90 (hardbound; ISBN 978 0 521 51407 1).

Given the substantial investment in the development of gravitational-wave detectors like the ground-based interferometers *LIGO* and *VIRGO*, the planned joint US–European space-based detector *LISA*, and the tremendously exciting new vistas on astronomy these detectors promise to open, it is not surprising that there has been a growing industry of numerical relativists characterizing the gravitational-wave signals that may be produced by various astrophysical phenomena. The solution of the General Relativistic equations describing the systems poses enormous computational challenges, already recognized thirty-two years ago when researchers in the field met at a workshop in Seattle to discuss the production of gravitational waves in astrophysics. Until recently, the proceedings of that workshop, edited by the numerical relativist L. Smarr, provided perhaps the best unified account of these astrophysical systems and the gravitational radiation they would produce. The subject has come a long way since then. Entering the field, however, was made difficult by the lack of any coherent overview of the many tools developed over the past several decades. This has now been redressed by Baumgarte & Shapiro, two leaders of the subject. Their book is destined to become the authoritative text on the subject for the next generation of numerical relativists.

Rather than providing a cookbook of numerical methods, the authors focus on the formulation of the numerical problem. Given the non-linear structure of the equations and difficult numerical issues that arise, such as both real and artificial singularities in the solutions, a successful numerical solution depends crucially on finding an appropriate way of posing the problem. A formulation of the standard Arnowitt–Deser–Misner 3 + 1 split of spacetime forms the core of the approaches developed in the text. Chapters are devoted to defining the initial conditions, the choice of coordinate systems, locating black-hole horizons, and a broadbrush description of numerical methods, including their advantages and disadvantages (shock-capturing *versus* smoothed-particle-hydrodynamics

schemes; finite-difference *versus* spectral methods; particle *versus* phase-space methods for collisionless systems).

At the heart of the subject, of course, are the applications. Here the text devotes several chapters that not only demonstrate the numerical methods in action, but describe major advances in relativistic astrophysics that numerical relativity has made possible. These include a wide range of phenomena, such as the formation of a black hole from a collapsing massive star or from a collisionless gas of particles representing a relativistic star cluster, the merger of the compact objects in binary-star systems composed of black holes and/ or neutron stars, and the gravitational waves that result. The application of numerical relativity to the solution of some fundamental questions in General Relativity, such as the formation of naked singularities, is described as well. For this reason, in addition to providing a superb, well-illustrated introduction to the subject, the book presents an up-to-date overview of the discoveries in the subject over the past few decades that would be of interest to a much wider readership.

The book is presented as a textbook for students, with hundreds of exercises scattered throughout as well as copious references to the literature. The text presumes the student already has a solid foundation in the basics of General Relativity. Advice is provided for using the book for either a two-semester course or a one-semester 'minicourse'. It is unlikely that many universities would offer such a highly specialized course, but as an introduction for a PhD student or more advanced researcher who wishes to enter the field of numerical relativity the book would be an invaluable resource. — AVERY MEIKSIN.

Galaxies in Isolation: Exploring Nature Versus Nurture (ASP Conference Series, Vol. 421), edited by L. Verdes-Montenegro, A. del Olmo & J. Sulentic (Astronomical Society of the Pacific, San Francisco), 2010. Pp. 302, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 722 3).

Hubble thought that most galaxies were randomly scattered across the field of night, apart from a few large, dense clusters, like Virgo and Coma. Shapley, on the other hand, concluded that most galaxies were to be found in groups and clusters. Statistical studies of correlation functions in 2- and 3-dimensions have largely supported Shapley. What, then, is an isolated galaxy, and why should one have a conference about them? A typical definition is a galaxy whose nearest neighbour (with diameter differing by a factor less than four or a brightness differing by a factor less than 16) is further away than some number (*e.g.*, 20 or 30) times the diameter of the galaxy you are looking at, and whose separation in radial velocity is more than 500 km/sec if this information is available. A sample so defined will consist of galaxies whose next major interaction is at least 1–3 Gyr into the future, and whose previous one was a comparable time in the past, if its current morphology looks undisturbed. The first large catalogue of such galaxies was compiled by Valentina Karachentseva (to whom the conference and proceedings were dedicated) in 1973, and she has recently completed another one.

As for why, introductory speaker Jack Sulentic pointed out the desire to separate effects of nature and nurture (interactions) in the formation and evolution of galaxies, which might be achieved by comparing isolated (mostly 'nature') galaxies with ones in crowded environments ('nurture'). A few interesting bullet points include, (*a*) at least some isolated ellipticals are probably fossil groups (the big one having swallowed all the little ones),

(*b*) isolated galaxies tend to be rather weak X-ray and radio sources, and (*c*) the galaxies in voids (regions with densities below the cosmic average) are not really more isolated than galaxies elsewhere and probably do not present any special problems for the standard ΛCDM model of structure formation.

My favourite phrase from the invited talks is "our parameter free tessellation-based watershed void finding technique", and my favourite from the posters (limited to an acronym-tempting one page each) is "a general characteristic of the LST is the MST". Three things can be said about the pictures: the cover image (isolated spiral NGC 7127 over the western — I think — horizon of the Alhambra) is perfectly lovely; the images of galaxies in the text are in rather smeary black and white and unnecessarily compressed, given that the volume adds up to fewer than 300 pages; and the customary pictures of participants on blank even-numbered pages suggest that the three essential liquids of astronomy — water, wine, and coffee — were generously provided, but that none of the people had names. — VIRGINIA TRIMBLE.

Annual Review of Astronomy and Astrophysics, Volume 48, 2010, edited by R. Blandford, S. M. Faber, E. van Dishoeck & J. Kormendy (Annual Reviews, Palo Alto), 2010. Pp. 723, 24 × 19·5 cm. Price $214 (print only for institutions; about £130), $84 (print and on-line for individuals; about £51) (hardbound; ISBN 978 0 8243 0948 0).

The annual apparition of *ARA&A* heralds the start of winter, when one can hunker down by the fire of an evening and catch up on what is going on in astronomy (presupposing one is no longer an observer!). And, as one might expect, in this year's volume there is a wealth of essential reading presented in the form of 16 benchmark reviews.

However, this volume starts with a well-deserved tribute to Geoffrey Burbidge who edited *ARA&A* for an exemplary 32 years — surely a feat beyond the normal call of duty (as well as a target for other editors to aim at!). And talking of editors, the next article is by an ex-editor of *these* pages, Donald Lynden-Bell, who holds forth on the questions that have motivated him through a long (and continuing) distinguished career of research (and who also adds a few choice ingredients to the spicy story of the foundation of the Institute of Astronomy at Cambridge).

Then we come to the serious business of the series, getting us up to date on a wide range of topics in astronomy, and the fashionable theme of the origin of planetary systems is well covered this year with discussion of the ingredients ('Cosmic silicates' by Henning, and 'Interstellar dust in the Solar System' by Mann), the solar nebula ('The birth environment of the Solar System' by Adams, and 'The inner regions of protoplanetary discs' by Dullemond & Monnier), and what we might get at the end of it all ('Exoplanet atmospheres' by Seager & Deming). To learn whether the parent stars to these planets will be well behaved we need to consult papers on 'Local helioseismology' by Gizon *et al.* — which offers the prospect of whole-surface monitoring of the Sun — and 'Physical processes in magnetically driven flares on the Sun, stars, and YSOs' by Benz & Güdel. And to find out how long the party can last, I recommend Soderblom's excellent essay on 'The ages of stars', in which, among many topics, the prospect of improving models through asteroseismological inputs is discussed.

On a wider stellar front, the notion of 'A universal stellar IMF' is examined by Bastian *et al.*, and looks to be plausible, while Portegies Zwart *et al.* give

a progress report on 'Young massive star clusters'. Further afield we look at 'Molecular clouds in nearby galaxies' with Fukui & Kawamura to see how local GMCs will throw light on star formation, *etc.*, in distant galaxies; and get a 'definitive' value of the Hubble Constant from Freedman & Madore (73 km s^{-1} Mpc^{-1}, or an age of the Universe of 13·7 ± 0·5 Gyr). Of course, whether that changes with time and distance is still *sub judice*, so it will doubtless help if 'Dark matter candidates from particle physics and methods of detection' (Feng) throws up some possibilities, while probing mass distribution *via* 'Strong lensing by galaxies' (Treu) will surely contribute valuable information. Naturally, a coherent picture must be compatible with history, as discussed by Morales & Wyithe in 'Reionization and cosmology with 21-cm fluctuations', where the distribution of redshifted neutral hydrogen offers clues to the early development of the Universe. And finally, the use of 'Smoothed particle hydrodynamics in astrophysics' (Springel) has wide application in many areas of the research covered in this vital series. — DAVID STICKLAND.

Annual Review of Earth and Planetary Sciences, Volume 38, 2010, edited by R. Jeanloz & K. H. Freeman (Annual Reviews, Palo Alto), 2010. Pp. 599, 24 × 19·5 cm. Price $234 (institutions, about £160), $89 (individual, about £61) (hardbound; ISBN 978 0 8243 2038 6).

This year's volume of *Annual Review of Earth and Planetary Sciences* includes a diverse palette of subjects that ranges from Saturn's rings to booming sand dunes. As usual, there surely is something for everyone here. And as usual, the book is beautifully presented and is a pleasure to read.

This year there is only one chapter directly related to climate change, in the form of a review of the effects of aerosol particles in the troposphere. Is global warming going off the boil? Chapters on tectonics and geodynamics include two reviews of the eastern Mediterranean region. Some remarkable systematic migrations of geologic style are identified that correlate with southward retreat of the Hellenic trench and the laying down of the slab on the 660-km discontinuity. The two subjects are linked together in chapters on the effect of the Tibetan plateau on the monsoon of East Asia, and the possible climate effects of late Neogene erosion of the Alps.

Seismology is represented by reviews of the 2008 M ~ 8 Wenchuan, China, event and the 2004 M ~ 9 Sumatra earthquake. Both of these caused extensive loss of life. The latter review is cross-disciplinary, including not only seismological data but also geodetic, gravity, hydroacoustic, and tsunami observations. A somewhat more exotic aspect of seismology is glacial earthquakes. These are caused by kilometre-scale ice-calving events at outlet glaciers in Greenland and Antarctica, and a chapter reviews this new class of earthquake.

The topical subject of mantle plumes is represented by a disappointing chapter that reiterates the standard model and dismisses alternatives by simply asserting that most people disagree with David Green. This chapter does, however, provide a useful summary of many geochemical issues associated with ocean-island basalts, including several observations and deductions which, in fact, are more in accord with theories of shallow provenance for volcanic regions. These include the 'mantle plume reservoir' being small, not at the core–mantle boundary, and bearing the geochemical signature of the upper mantle. Helium, and other noble-gas-isotope data, are declared not to require a deep primordial origin. One wonders if mantle plumes would have been invented today, given the information we now have available to us. An alternative way in

which melt can be formed in the Earth is described in a chapter on the frictional melting of rocks by various processes. This chapter harmonizes nicely with the final chapter of the book, which is a review of the lithosphere–asthenosphere boundary that includes discussion of the nature of these two layers and the possible ubiquitous existence of melt in the asthenosphere.

The chapter on "isoscapes" (a new one on me!) presents information and ideas that are likely to be less familiar to readers. This chapter summarizes the "isotope landscape" that results from biogeochemical processes. Biology *per se* is represented by chapters on marine species. These include whales, armoured fish (placoderms), and the fish fauna of the Devonian Gogo formation in Western Australia.

Planetary science is represented by reviews on Saturn's rings and the formation of Martian river valleys and planetesimals, and finally those booming sand dunes! In this context, booming can evidently include rumbling, music, and barking, and we are urged not to "turn a deaf ear" to this strange and interesting phenomenon. — GILLIAN FOULGER.

SOHO-23: Understanding a Peculiar Solar Minimum (ASP Conference Series, Vol. 428), edited by S. R. Cranmer, J. T. Hoeksema & J. T. Kohl (Astronomical Society of the Pacific, San Francisco), 2010. Pp. 336, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound: ISBN 978 1 58381 736 0).

The recent solar minimum is remarkable in that it marked the period of lowest solar activity since the space age began. In 2009, the visible hemisphere of the Sun was spotless for over 70% of the time, with over 800 spotless days since 2004, nearly twice what is usual. The SOHO-23 workshop was convened when the Sun was still in the depths of this period — late 2009 September, and was attended by 95 scientists who work in a broad range of topics, ranging from helioseismology to the outer heliosphere. The 49 papers, including two keynote reviews, reflect this, with categories covering the solar interior, which is the seat of the Sun's activity, photosphere and chromosphere, corona, solar wind, heliosphere, and — what remains a staple for those brave enough to stick their necks out — solar-cycle prediction.

Although the minimum is exceptional by recent (*i.e.*, last 50 years) standards, such low levels of solar activity are by no means unprecedented: as the article by Sheeley shows, our grandparents knew of similar minima in 1902 and 1913. But now we have much more sophisticated instrumentation, in particular helioseismometers that give us rotation speeds at various levels in the solar interior. Such measurements extend over a sufficiently long period that the cyclical variation of mode frequencies can be examined. The instruments on *SOHO* feature prominently in this, of course, but ground-based instruments such as the *BiSON* and *GONG* global arrays go back much further so have some advantage here. The articles by Thompson, Fletcher *et al.*, and Salabert *et al.* indicate interesting frequency shifts in individual low-degree modes, related to magnetic flux in sub-photospheric layers. There is only one article, by Miesch, on the solar dynamo, and although short it is informative on the long-term evidence for the periodic yet chaotic nature of the dynamo.

The total solar irradiance and solar ultraviolet emission are discussed by Woods, with graphic illustrations. Other papers along these lines worth noting include that by Curdt & Tian who compare measurements with the *SOHO SUMER* ultraviolet instrument with the *SOLSTICE* instrument on *UARS*: the variations in the Lyman-alpha emission are due to particular features, not the

quiet Sun itself. This leads to the article by Rast on the reality of the quiet Sun: anything larger than granules appear to be dominated by magnetic, not thermal, changes, so the truly quiet Sun only exists at a level of not more than 5%. Out in the solar wind, measurements show lowered densities and temperatures at 1 AU (Cranmer), while even further out the veteran *Voyager* spacecraft, discussed by Richardson, show that the reduced solar wind pressure has resulted in the termination shock moving inwards by up to 5 AU.

There are indications that solar activity is slowly increasing, so these Proceedings are a timely look-back on what may be simply an anomalous period or may usher in a new era in reduced solar activity. Either way, this book, which is well produced and illustrated with coloured figures, should be of interest to a wide readership. — KEN PHILLIPS.

Solar-Stellar Dynamos as Revealed by Helio- and Asteroseismology

(ASP Conference Series, Vol. 416), edited by M. Dikpati, T. Arentoft, I. González Hernández, C. Lindsey & F. Hill (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 597, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound: ISBN 978 1 58381 712 4).

This fat volume contains the proceedings of a combined *GONG–SOHO* Workshop held at HAO in Boulder in 2008 August, and includes about 100 individual contributions. Cumulatively, they do provide an overview of activity in the field, though I can't help wondering whether it still makes sense to print such a plethora of short papers when they could all be made available on the web, and most of the results will sooner or later appear in regular journals.

The dynamo problem is 90 years old, helioseismology has reached its half-century — but asteroseismology is still young: *CoRoT* was only launched in 2006, and *Kepler* already postdates this conference. So what is new here?

Local helioseismology is being applied to probe meridional and zonal flows in the convection zone and to explore the subsurface structure of active regions and sunspots. On a global scale, the search for g-modes, along with investigations of deep-seated torsional oscillations, still continues but the main controversy is over the abundance of heavy elements in the solar plasma. Spectroscopy combined with numerical modelling of photospheric convection suggests a reduction of 10% in overall metallicity — enough to make solar models incompatible with helioseismology. Can this be accommodated by adjusting opacities or even the equation of state, or will helioseismic observations force a revision of the basic physics (as in the old neutrino problem)?

On the theoretical side, large-scale computation is booming. Simulations of supergranular-scale convection and magnetoconvection grow ever more realistic, as do the latest numerical models of sunspots. On a larger scale, there are great efforts to model the tachocline and to explore its influence on the solar dynamo, but there is not yet a realistic model of the solar cycle. Perhaps the next such workshop will have more to tell us. — NIGEL WEISS.

Numerical Modeling of Space Plasma Flows: ASTRONUM–2009

(ASP Conference Series, Vol. 429), edited by N. V. Pogorelov, E. Audit & G. P. Zank (Astronomical Society of the Pacific, San Francisco), 2010. Pp. 336, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 738 4).

This volume contains a collection of nearly fifty papers presented at the 4th annual International Conference on Numerical Modeling of Space Plasma

Flows held in summer 2009 in Chamonix, France. The scientific areas treated cover an enormous range of topics in astrophysics and space science, including turbulence in the intergalactic medium, jet propagation in active galactic nuclei, physical processes in star formation, stellar evolution and supernovae, coronal heating and dynamics, and solar-wind interaction with planets and the interstellar medium. Although these papers are directed towards specific scientific goals as briefly discussed in each, the presentations mostly emphasize the numerical methods employed, and discussions of accuracy, limitations, and future directions. In addition, two of the six sections of the book are devoted specifically to methods and algorithms, and data handling and visualization. The other sections somewhat loosely divide the more science-orientated papers into those concerning turbulence and cosmic-ray transport, astrophysical flows, space-plasma flows, and kinetic and hybrid simulations. Although these presentations, each on average seven pages long, are generally too brief for direct pedagogical purposes, the book nevertheless provides a useful concentrated view of current research in numerical simulation of astrophysical fluids, and a starting point for more detailed examinations of the relevant literature. The volume has been produced to a pleasingly high standard of full-colour publication throughout, as required to illustrate the results of many of the high-resolution simulations presented within. — STAN COWLEY.

Modern Plasma Physics Volume 1: Physical Kinetics of Turbulent Plasmas, by P. H. Diamond, S.-I. Itoh & K. Itoh (Cambridge University Press), 2010. Pp. 417, 25 × 18 cm. Price £75/$130 (hardbound; ISBN 978 0 521 86920 1).

The present volume is the first in a projected series of three that is aimed at advanced graduate students who want to know about modern developments in plasma dynamics. Volume 1 is largely concerned with the theoretical framework for understanding turbulent behaviour in plasmas, and essential, tried-and-tested topics such as quasi-linear theory, resonance broadening, three-wave interactions, and modulational instabilities are covered in great detail over several chapters which form the core of the book. Several chapters also make use of the concepts of wave kinetics developed by Whitham and others, which involve wave action and quasi-particles. The material presented is conceptually tough and at the cutting edge of modern classical physics, but the reader is led through it with clear explanatory detail and many instructive examples. The authors are to be particularly commended for their very readable introductory chapters, the first of which outlines the purpose and scope of the book. The second provides a comprehensive overview of the conceptual foundations of plasma turbulence. The idea of the dressed test particle in a kinetic-theory context is introduced early on, together with the generic ideas of scale cascades that underpin Kolmogorov's theory of fluid turbulence and the power of symmetry arguments in the concept of self-similarity. This provides a strong pedagogical foundation to a well-presented, comprehensive text that should prove invaluable to research students in the fields of space and astrophysical plasmas, as well as laboratory plasmas. I look forward with anticipation to Volume 2, which deals with the crucial topic of structure formation in plasmas. — TERRY ROBINSON.

Units of Measurement: Past, Present and Future. International System of Units, by S. V. Gupta (Springer, Heidelberg), 2010. Pp. 158, 23 × 15 cm. Price £89/$129/€99·95 (hardbound; ISBN 978 3 642 00737 8).

If you don't happen to know how many *rupees* make a *Lakh*, this book is the place to go, because the first chapter deals with the history of metrology in India, as used in the *Vedas*, the *Gita*, and so forth. There are lengths from that of a dust particle coming off the wheel of a chariot (the *Rajakhan*) on up (but no very long ones); times from the *permanu* (about 2·6 μs) up to a day of Brahma, the *Kalpa*, which is 4·32 billion solar years; masses from the *Masa* (about a gram and used in measuring gold) on up to at least the *Maundh* (100 Troy pounds and dating only from the British period); and powers of ten from one (*Das*) to 10^{18} (*Das pradharya*). Oh, and a *Lakh* is 10^5, a *crore* 10^7, and still probably in more common use for money than our more familiar 10^3 and 10^6. I first heard the word from the daughter-in-law of C. V. Raman, recounting a conversation with her late father-in-law, in which he responded to one of her ideas with the comment, "We will make Lakhs and Lakhs of rupees" which I misheard as "lots and lots".

The rest of the book is very much less fun, though clearly we need to know at least portions of it to report results of observations and calculations. The author is not just pro-SI; he is violently anti-anything-else. Of our familiar units, only the astronomical unit (incorrectly written as ua rather than AU) and the Jansky even appear; no solar masses, parsecs, *etc*. Particle physicists are deprived of their picobarns — only the barn, for nuclear physics, is allowed. Folks who light stages must do without the unmentioned foot-candle, though the phot and stilb are duly condemned, and the lumen and lux approved. No calories and no Gauss and so forth, some of these it seems actually prohibited in India.

The book has some more cheerful parts, including capsule biographies of "scientists associated with derived units", ranging from Newton and Pascal to Becquerel, Gray, and Sievert. Section 5.1 explains how to clean a standard kilogram, though 8.4.1 lists three more fundamental kg definitions currently under consideration (in terms of energy equivalent of a large number of photons, or the De Broglie–Compton frequency — a similarly large number — or a precise number for Planck's constant).

If you are an aging astronomer (not, of course, as old as I), you will probably be too annoyed to care by the time you get to the relevant pages that the author confuses h and $\hbar$ (Table 6.6), giving the same number for both (in Js of course), and that $1 \text{ cm}^3 = 10^{-2} \text{ m}^3 = 10^{-6} \text{ m}^3$, where we think the middle step should be $(10^{-2} \text{ m})^3$. I do not object to the metre, since the volume is clearly in British English, but the claim that kilogram per metre cube is OK but kilogram per metre cubed and kilogram per cubic metre are forbidden sticks in my bilingual throat.

One item of real merit (not actually belonging to the book in hand) is that, for the most part, most of the world has managed to stick together on matters of weights and measures from the 'Metre Convention' in Paris in 1875 right through to today's BIPM. The USA has, of course, been the least-cooperative major nation, not just on metric unity and SI in general, but in switching from Centigrade (officially declared the everyday unit of temperature in the early 1900s) to Celsius. I think we make science unnecessarily difficult for our

children by requiring them to learn new units at the same time they are trying to learn new ideas. Nor is the UK entirely blameless in this matter. — VIRGINIA TRIMBLE.

NIST Handbook of Mathematical Functions, edited by F. W. J. Olver, D. W. Lozier, R. F. Boisvert & C. W. Clark (Cambridge University Press), 2010. Pp. 952 + CD, 28 × 22 cm. Price £65/$99 (hardbound; ISBN 978 0 521 19225 5), £35/$50 (paperback; ISBN 978 0 521 14063 8).

Those of us who occasionally need to find the zeros of a Bessel function, can't quite remember the definition of a Gegenbauer polynomial, or are confused about the difference between Kelvin and Thomson functions, will generally have on our shelves a well-thumbed copy of A&S (Abramowitz & Stegun, *Handbook of Mathematical Functions*). Though these days, the place of first resort is more likely Google or Wikipedia.

This book is essentially an expanded and updated version of A&S, but it also comes with a CD, and with web-links, which enable one readily to access far more material, including some of the original references. As such, it is a welcome addition to one's reference collection. It contains far more material than A&S, especially welcome being an up-to-date chapter on numerical methods and approximations.

But in some ways, more is less. Many of the definitions are now obscured by pure mathematical pedantry (these are the people who get worried that the function $f(x) = x/x$ is not continuous at $x = 0$), which gets in the way of a simple soul looking for a quick answer. The attempt to show the structure of complex functions using colour-coded surfaces in 3D does not really work, and the colouring code is not always explained. And simple things, like a table of the zeros of Bessel functions, which can be found *via* Google, or using a single command in Mathematica, are no longer there. I particularly regret the replacement of easy approximate analytic formulae, which one can use in one's own programs, by long-winded descriptions of how one can evaluate functions in principle or references to software packages.

Overall, this book is worth having, if you are into this kind of thing. It is well-structured and fairly easy to find one's way around. The only complaint in this regard is that the typesetting of the index makes it very hard to use (it should be more compact — compare with A&S to see how it should be done). Thus looking up Kelvin and Thomson functions took a while. Thomson functions are not mentioned, but then I suppose one really should know why. — JIM PRINGLE.

So You Want a Meade LX Telescope!, by L. Harris (Springer, Heidelberg), 2010. Pp. 233, 23·5 × 15·5 cm. Price £22·99/$29·95/€29·5 (paperback; ISBN 978 0 4419 1774 4).

This book is a lot more than the main title suggests since it helps a prospective telescope purchaser select and use the LX200 and other Meade models. And it isn't only focussed on promoting Meade hardware: it starts off by warning the reader against buying a top level telescope too soon and gives some other choices. This is an ideal book for those already owning a Meade telescope and especially as a stimulus to get existing telescopes out of mothballs and back into use. It covers a choice of accessories with not all of them coming from Meade, *e.g.*, the very-well-made Milburn Wedge. It shows how to upgrade the instruments' firmware and covers such diverse areas as set-up, adjustment (including a good section on collimation), maintenance, and use.

A range of software applications available for the instruments is described and the use of each is explained. It starts by looking at the programs supplied by Meade for the instruments and their accessories and then moves on to other commercially available programs for telescope control, image acquisition, and processing. Indeed, many of the strengths of the book lay with giving practical tips on how to adjust the telescope by using several readily available software aids. Several useful programs are described to help with such tricky items as periodic-error correction and polar alignment. WWW resources are given regularly throughout the book to point the reader in the direction of additional information. The use of such tools as Hartmann and Bahtinov masks are introduced to assist with focussing. The book gives an excellent introduction to CCD-camera techniques, auto-guiding, and adaptive optics; it also gives good descriptions of the use of flat-field, bias, and dark images.

The book contains a section on advanced software for astrometry and automatic asteroid detection and a comprehensive description of the excellent DC3 Dreams ASCOM applications from Bob Denny. For those who are interested in monitoring weather satellites directly, the necessary hardware and techniques are described.

One criterion for the success of a book is how much new information is learned from it. I have owned GOTO telescopes for many years. There is lots of advice in this book which I will follow up and try. Although the book majors on the Meade LX range it will be of value to other GOTO-telescope users. I will be referring to my copy on a regular basis. — TOM BOLES.

Patrick Moore's 2011 Yearbook of Astronomy, edited by P. Moore & J. Mason (Macmillan, London), 2010. Pp. 364, 20 × 13·5 cm. Price £16·99 (paperback; ISBN 978 0 230 75209 2).

The welcome annual apparition of *Patrick Moore's Yearbook of Astronomy* provides something for everyone with an interest in the subject. Beginning with monthly star charts and the predictable astronomical phenomena for 2011 and concluding with observing notes for a selection of interesting topics (variable stars, double stars, nebulae, and clusters) plus contact information for a large number of astronomical societies in the UK, the practical observer is well catered for. (Except that I noted, for the Crayford Manor House Astronomical Society, that the address of the secretary is several years out of date! Beware — there may be others.)

For the armchair astronomer, more delight will probably be had from the 'Article section', which holds eight excellent essays on a range of topics. The first is by David Harland who brings us right up to date on the question of water, in the form of ice, on the Moon, and the encouraging conclusion is that it is there waiting for the first colonists. Richard Baum then recalls the earliest investigations into the atmosphere of Venus in the 18th and 19th Centuries. The remarkable observational productivity of the Japanese since the time of Honda is enthusiastically described by Martin Mobberley; it does rather suggest that their weather is notably better than ours. Fred Watson then indulges in some galactic archaeology to reveal, in an inspirational way, the present view on the structure and evolution of the Milky Way. The fifth article is a short history of the Norman Lockyer Observatory, charting its foundation, a period of productivity (although the work of Rimmer, often mentioned in the papers of Roger Griffin in these pages, was disappointingly not discussed), its decline and near abandonment in the early 1980s, and its subsequent rise as a major public-outreach facility. Next John Mason describes the Giacobinid meteor showers

— watch out for what might be a good one next October 8th. Of interest to lunar observers, if they want to peep over the limb, will be Paul Abel's article on librations of the Moon. And finally, Allan Chapman discusses the involvement of the Royal Society in astronomy (before the RAS came along).

So whether it's clear or cloudy, make sure you have a copy to hand. — DAVID STICKLAND.

————————

THESIS ABSTRACT

THE X-RAY PROPERTIES OF COOL-CORE GALAXY CLUSTERS

By Helen Russell

In this thesis I explore the structure and evolution of cool-core galaxy clusters with the *Chandra X-ray Observatory*. The radiative-cooling time of the hot intracluster medium (ICM) drops below a Gyr in the centre of many galaxy clusters, suggesting that the gas is cooling rapidly out of the X-ray band. However, spectroscopic evidence from the *Chandra* and *XMM–Newton* observatories indicates that cooling is substantially reduced below the predictions of simple cooling-flow models. Detections of cold gas and star formation confirm that only a small fraction of the gas is actually cooling down to low temperatures. *Chandra* observations of nearby clusters now suggest that the radiative cooling is compensated by heating from the central active galactic nucleus (AGN), which generates sound waves, weak shocks, and buoyantly rising bubbles. This thesis studies radiative cooling, AGN heating, and cluster mergers, which produce the complex and dynamic environment observed in cool-core clusters.

Studies of the key X-ray gas properties in cluster cores require a reliable method of de-projecting the cluster emission. I develop and validate the de-projection routine DSDEPROJ and compare the results with the commonly used XSPEC routine PROJCT. Using simulated clusters and *Chandra* observations of nearby clusters, I show that DSDEPROJ produces stable de-projection results for galaxy clusters.

I then analyse a sample of new and archival *Chandra* observations of clusters hosting brightest cluster galaxies (BCGs) with excess mid-IR emission, which is interpreted as star formation. I present maps and de-projected radial profiles of the ICM temperature and density to study the X-ray environment of these objects. The results show a strong correlation between the rate of cooling in the ICM and the rate of star formation detected in the IR, suggesting that star formation is fuelled by gas condensing out of the ICM. The observations indicate that AGN heating is finely tuned to the ICM cooling and prevents all but a few percent of the gas which could cool from doing so.

Using a *Chandra* observation of H1821+643, the only low-redshift galaxy cluster to contain a highly luminous quasar, I investigate the impact of the quasar on the surrounding ICM. By simulating and subtracting the point-spread function of the quasar, I determine the ICM gas properties close to the point source and find that H1821+643 appears to be a typical strong cool-core cluster.

Although there is some substructure inside the central 100 kpc, the quasar does not appear to have significantly affected the large-scale cluster properties.

Finally, I analyse the spectacular shock fronts revealed by a *Chandra* observation of the merging cluster Abell 2146. The X-ray image and temperature map show a cool-core sub-cluster with a ram-pressure-stripped tail of gas just exiting the disrupted primary cluster. The sub-cluster is preceded by a bow shock, and a slower upstream shock is observed propagating in the opposite direction through the outer region of the primary cluster. Based on the measured shock velocities and the strength of the upstream shock, I argue that the mass ratio between the two merging clusters is between three and four to one. — *University of Cambridge; accepted 2010 May.*

A full copy of this thesis can be requested from: hrr27@ast.cam.ac.uk

---

OBITUARY

Robert Harry Koch (*1929–2010*)

Robert Koch was born in York, Pennsylvania, on 1929 December 19, and was educated locally, graduating from York Catholic High School in 1947, and earning a bachelor's degree in mathematics at the University of Pennsylvania (UP) in 1951. After serving in the Army Quartermaster Corps until 1953, he returned to UP to gain a master's degree in astronomy in 1955.

Bob's research interests then took him to the Steward Observatory of the University of Arizona, where he collected a second master's degree in astronomy in 1957 before returning to UP to add a doctorate in astronomy to his collection in 1959. A spell of teaching in the Four-College Astronomy Department in Amherst, Massachusetts, lasted until 1966, when he spent a year at the University of New Mexico teaching and building a research observatory, after which he returned 'home' to UP at the start of a 29-year career, being appointed professor there in 1969. As director of UP's Flower and Cook Observatory from 1989 to 1994, Bob presided over an institution that enabled him to pursue his abiding interest in binary stars.

And it was in that context that I first came into contact with Bob. Having discovered that I could get quite respectable orbits of hot, close-binary stars from archived high-resolution spectra taken with the *International Ultraviolet Explorer*, I entered some proposals for new observations for such objects to the time-allocation panel, and was persuaded by Yoji Kondo to work with Bob, who had made complementary proposals to the US panel. The collaboration prospered for several years until satellite operations ceased, resulting in a number of papers published in these pages and elsewhere. It also enabled Bob, with wife Joanne, to spend six months in England, which we all enjoyed greatly.

Our friendship continued thereafter and it was a great shock to learn that Bob had been diagnosed with a brain tumour in 2010 August, and I was extremely sad to hear of his death on October 11. We have not only lost a fine scientist and teacher but also a man of diverse interests: he was an inveterate traveller, a keen

ornithologist, a budding mandolin player, and someone with a lively interest in almost everything. He is survived by wife Joanne, sons Thomas and James and daughters Elizabeth and Patricia, and will be greatly missed by them, me, and many members of the astronomical community. — DAVID STICKLAND.

———————

Here and There

PERHAPS IN NORWAY?

The Sky At Night: Patrick Moore, Dr Chris Davis and Professor John Brown discuss the sun. — *Sunday Times*, Culture section, 2010 April 4, TV programmes for BBC1/2.

TO ENCOURAGE DEBATE, PERHAPS?

Our Hotel has 8 meeting rooms with different capacities equipped with projection screen, annoy systems, flipcharts. — *Guest Handbook* at a conference hotel in Santiago de Compostela.