1994A&A...281...73M

Astron. Astrophys. 281, 73–89 (1994)

ASTRONOMY
AND
ASTROPHYSICS

Photometric variations of Ap stars*

J. Manfroid[1]** and **P. Renson**[1]

[1] Institut d'Astrophysique, Université de Liège, Avenue de Cointe 5, B-4000 Liège, Belgium

Received April 22, accepted June 21, 1993

Abstract. The photometric variations of seven Ap stars have been analyzed from observations mainly obtained in the framework of the Long-Term Photometry of Variables project at ESO. New values for the periods and detailed light curves in the $uvby$ system are provided. α Scl is shown to display anomalous variations that set it apart from the other stars.

Key words: stars: chemically peculiar – techniques: photometric

1. Introduction

Many stars cannot be adequately studied during regular observational runs of a few weeks as generally attributed in mission observatories such as ESO. Ap stars may fall into this category for several reasons: (i) they may just have a very long period; (ii) aliasing with the 1-day observational sampling period may prevent to obtain sufficient data over a small number of nights at a single observatory; (iii) unusual characteristics of the light curve may request observation of many cycles in order to confirm the presence and stability of the feature (e.g., dips observed in the lightcurves of TW Col, Renson & Manfroid 1992, and 46 Eri, Manfroid & Renson 1989); (iv) they may show multi-periodic variations probably due to binarity (e.g., τ^9 Eri, Manfroid et al. 1985) which also request numerous observations over a long time interval.

Fortunately, the Long-Term Photometry of Variables project (LTPV) started at ESO in 1982 (see Sterken 1983, 1986) is concerned with stars displaying a photometric behaviour of such a nature that observations over an unusually long time interval are necessary. Several Ap stars were included in the LTPV programme. Most of these stars had already been observed by us in previous observing runs but the data could not lead to definite conclusions. The analysis of the complete observations is presented in the following sections.

2. The observational material

Part of the LTPV data is already published as a catalogue (Manfroid et al. 1991a,b). A second batch of data is to be published soon (Sterken et al. 1993). Those data can also be retrieved from the Strasbourg CDS center. The LTPV observations were made with various photometric equipments. Despite homogenizing procedures described in the above-mentionned references, a total of 7 distinct – irreconcilable – photometric systems must be considered. Moreover, observations in six previous observing runs (1977–1981) constitute as many additional systems. The details of these observations are given in Table 1.

Rigorous homogenization of the observations carried out at the Danish 50 cm before 1982 was not attempted because of technical reasons, one of them being that there were few constant stars in common. Although these data should in principle be compatible, we choose to consider them as pertaining to separate photometric systems. Moreover, the differential analysis we use (see Sect. 3) takes care of systematic differences between systems, i.e., performs some homogenization.

Data relative to the programme stars are given in Table 3. Comparison stars are also listed, as are the number of useful differential observations and the total time interval covered by these observations. The "Rns" number refers to the catalogue of Ap and Am stars by Renson (1991). The star HD 6178 = σ Scl appears in the list both as a comparison and as a programme star because it has been found to be slightly variable (see Sect. 4).

3. Analysis of the variations

Ap stars are normally characterized by very regular periodic variations, so the observations made within a well-defined photometric band can be fitted with the following model

$$m(t) = A + \sum_{i=1}^{I} B_i \cos\left(\frac{2\pi i\,(t - t_0)}{P} + \phi_i\right) \quad (1)$$

where m is the magnitude, P the period, I the total number of harmonics, t the time and t_0 the origin of time. More generally, we have to consider the situation where (i) the star is multiperiodic (case of, e.g., HD 25267= τ^9 Eri, Manfroid et al.

Send offprint requests to: J. Manfroid

* Based on observations collected at the European Southern Observatory, La Silla, Chile

** Research Director NFSR

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1994A&A...281...73M

Table 1. Observing log. All observations later than October 1982 were part of the LTPV program. The telescopes used are the Danish 50 cm, the Bochum 61 cm, the ESO 50 cm and the Strömgren Automatic Telescope. The numbers assigned to the photometric systems used in the LTPV programme are identical to those used by Manfroid et al. (1991) and Sterken et al. (1993). Higher numbers (> 9) are given to the systems of the various other observing runs

Months	$JD_\odot - 2\,440\,000$	Observers	Telescopes	Systems
July 1977	3342–3356	J. Manfroid	Danish	11
July 1978	3724–3747	J. Manfroid	Bochum	12
June 1979	4025–4049	J. Manfroid	Danish	10
March 1980	4310–4336	J. Manfroid	Danish	2
December 1980	4578–4602	J. Manfroid	Danish	3
September 1981	4859–4878	J. Manfroid	Danish	13
October 1982	5245–5273	O. Stahl	Bochum	1
December 1982	5295–5325	M. de Groot	Bochum	1
April 1983	5442–5459	O. Stahl	Bochum	4
August 1983	5562–5586	F.-J. Zickgraf	ESO	4
September 1983	5588–5608	H.-A. Ott	ESO	4
December 1983	5676–5702	O. Stahl	Bochum	4
July 1984	5898–5911	R. Schulte-Ladbeck	Bochum	5
August 1984	5914–5944	T. Hageman	Bochum	5
September 1984	5949–5978	H. Hensberge	Bochum	5
January 1985	6066–6098	H.W. Duerbeck	ESO	5
March 1985	6135–6154	O. Stahl	ESO	9
June/July 1985	6222–6281	F. Decker, H. Cuypers	Bochum	9
August 1985	6287–6297	A. Bruch	Bochum	9
September 1985	6304–6319	A. Bruch	SAT	7
November 1985	6380–6411	A. Reitermann	SAT	7
December 1985	6412–6443	F.-J. Zickgraf	SAT	7
February 1986	6475–6496	M. Burger	SAT	7
March 1986	6498–6521	A. Jorissen	SAT	7
June 1986	6581–6609	H. Steenman	SAT	7
July 1986	6612–6646	R. Madejsky	ESO	6
August 1986	6658–6675	A. Figer	SAT	7
September 1986	6677–6702	R. Duemmler	ESO	6
October 1986	6712–6732	M.V. Mekkaden	ESO	6
November/December 1986	6764–6782	A. Heck	ESO	6
July/August 1987	6996–7040	H.W. Duerbeck, A. Bruch	ESO	6
September 1987	7041–7069	A. Jorissen	ESO	6
October 1987	7072–7100	R. Duemmler	ESO	6
December 1987/January 1988	7133–7180	Y.K. Ng, E. Bibo	SAT	7
March 1988	7228–7236	A. Bruch	ESO	6
March/April 1988	7237–7259	A. Bruch, N. Vogt	ESO	8
January 1992	8645–8660	M. de Groot	SAT	7

1985, or, possibly, HD 37151, North 1984, 1993) and, (ii) observations made in several photometric systems must be merged. The former case is handled by surperposing the various periodicities. Merging different photometric systems is theoretically quasi-impossible (see, e.g., Manfroid & Sterken 1992; Manfroid 1992; Sterken & Manfroid 1992). However, because of the small amplitude of the spectral variations generally displayed by Ap stars, a first-order approximation is valid: we consider that the data sets of different systems can be homogenized via a simple zero-point shift in the differential measurements. Consequently, the general form of Eq. (1) becomes

$$m(t) = \sum_{s=1}^{S} A_s + \sum_{j=1}^{J} \sum_{i=1}^{I} B_{j,i} \cos\left(\frac{2\pi i (t - t_0)}{P_j} + \phi_{j,i}\right) \qquad (2)$$

Index s denotes the photometric system, and j a particular component and its overtones. If a Gaussian distribution is assumed for the observational errors, a standard deviation σ_k can be assigned to each measurement m_k, and a maximum likelihood estimate of the parameters of Eq. (2) can be obtained by minimizing the chi-square merit function

$$\chi^2 = \sum_{k}^{K} \left(\frac{m_k - m(t_k; \boldsymbol{A}, \boldsymbol{B}, \boldsymbol{P}, \boldsymbol{\phi})}{\sigma_k}\right)^2 \qquad (3)$$

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1994A&A...281...73M

Table 2. Symbols used in Figs. 1–9 to represent the various instrumental systems

System	Symbol	System	Symbol
1	+	8	○
2	□	9	■
3	△	10	★
4	×	11	▲
5	✳	12	▼
6	◇	13	◆
7	●		

The parameters are

$$\boldsymbol{A} = \{A_s\}\ (s = 1, \ldots, S),$$
$$\boldsymbol{B} = \{B_{j,i}\}\ (j = 1, \ldots, J; i = 1, \ldots, I),$$
$$\boldsymbol{P} = \{P_j\}\ (j = 1, \ldots, J),$$
$$\boldsymbol{\phi} = \{\phi_{j,i}\}\ (j = 1, \ldots, J; i = 1, \ldots, I).$$

This methods allows to determine the zero-point shifts together with the period(s) and the parameters of the lightcurve. Initial guesses of these quantities must be provided. This can be done by running the method with a limited set of parameters: the shifts can be estimated by setting $i = j = 0$, and trial period(s) can be deduced with $i = 1$ or 2, or by running other period-searching algorithms such as those proposed by Renson (1978a, 1980; see also Manfroid et al. 1991c) or by Deeming (1975).

Tables 4 and 5 list the parameters deduced for each star. The lightcurves are presented in Figs. 1–9. The symbols used to represent the various photometric systems are listed in Table 2. In each case, t_0 has been chosen as an integer Julian Day close to the deepest extremum.

4. Notes on individual stars

4.1. α Scl = Rns 1490

Spectral anomalies – e.g., underabundance of O and He, and overabundance of Cr, Ti and Sr – were found by Jugaku & Sargent (1961). They concluded to a spectral type of about B4V, with possible variations. The same spectral type was given by Buscombe (1962) in his list of southern fundamental stars, while Cousins & Stoy (1963) preferred to list α Scl as a B8IIIp star. The B8IIIp (He weak) type was also attributed by Guthrie (1965) and by Jaschek & Jaschek (1966) who noticed that CII λ4267 is particularly strong. The atmospheric parameters of this and other He weak stars have been studied by Norris (1971). α Scl appeared in lists of early-type stars near the southern galactic pole: Slettebak & Brundage (1971) concluded to a B4Vp type, while Bond et al. (1971) simply list it as Bp (He wk). The peculiarity also shows up in the UV: the Sky Survey Telescope (S2/68) onboard the TD1 satellite shows a large δ_{1400} index (Jamar et al. 1978).

The coexistence of features characteristic of both fast and slow rotators, viz broad, diffuse, He I lines and hydrogen and CII lines with sharp cores, led to the inclusion of α Scl in the "sn" class (Abt 1979, Brown et al. 1984, Shore et al. 1987). The variable lines of CIV at $\lambda\lambda$ 1548, 1550 are indicative of a variable, magnetically-controlled, stellar wind (Shore et al. 1987).

According to Vilhu (1978), α Scl is a long-period spectroscopic binary.

From intensity variations of the He line λ4026, Pedersen (1979) deduced a probable period between 22 and 26 days. Borra et al. (1983), using only 7 magnetic-field measurements and Pedersen's data, concluded that the period may be either $19\overset{\mathrm{d}}{.}4$ or $16\overset{\mathrm{d}}{.}7$, or shorter than 1 day ($0\overset{\mathrm{d}}{.}949$, $0\overset{\mathrm{d}}{.}486$).

Observations made in September 1981 (Table 1, #13) only allowed Manfroid & Renson (1983b) to point toward a period "of the order of 15 days". Using more sophisticated reductions of the same data, Mathys & Manfroid (1985) preferred to keep Borra et al.'s choice of values. Photometric measurements by Kurtz & Marang (1987) gave a period of $0\overset{\mathrm{d}}{.}98$ or $58\overset{\mathrm{d}}{.}8$, the latter one giving a reasonably good fit with the seven magnetic observations. However, the amplitude is very small, and those authors consider the result to be only marginally significant. Finally, Shore et al. (1990), using observations of the CIV intensity variations by the IUE satellite, together with 16 new magnetic field measurements, obtained the period $21\overset{\mathrm{d}}{.}654 \pm 0\overset{\mathrm{d}}{.}020$. Combining this with the photometric observations by Pedersen, they concluded to a period $21\overset{\mathrm{d}}{.}647 \pm 0\overset{\mathrm{d}}{.}009$. However, neither photometry in the Johnson U band by Kurtz & Marang (1987) nor Geneva $B1$ or U photometry seemed to agree with this period.

Clearly additional data were needed to solve the problem. This justified the inclusion of α Scl in the LTPV programme.

In their vast majority, the photometric data agree very well with the period

$$P = 21\overset{\mathrm{d}}{.}652 \pm 0\overset{\mathrm{d}}{.}008$$

(see Fig. 1), i.e., within the uncertainty of the results of Shore et al. (1990).

Let us note here that the precision we quote for periods is determined rather empirically on the basis of the chi-square analysis, but also by comparing the periods obtained for the different colors, and by visual inspection of phase diagrams relative to slightly differing periods. The precision depends on many factors, i.e., the total time interval, the precision of the observations, their frequency and time distribution, the number of comparison stars, the amplitude and the shape of the light curve, etc. All this explains the widely different precisions attributed to the periods of the various stars in the present analysis.

Because of their relatively high intrinsic noise, the data of Kurtz & Marang (1987) alone do not allow a good period determination for α Scl. However, they can be phased satisfatorily with the above-mentioned period. The same conclusion can be found from a subset of photometric observations in the Geneva system kindly provided by North (1993).

In order to obtain a good chi-square fit to the *uvby* observations, we removed all data obtained between JD 2 446 381 and

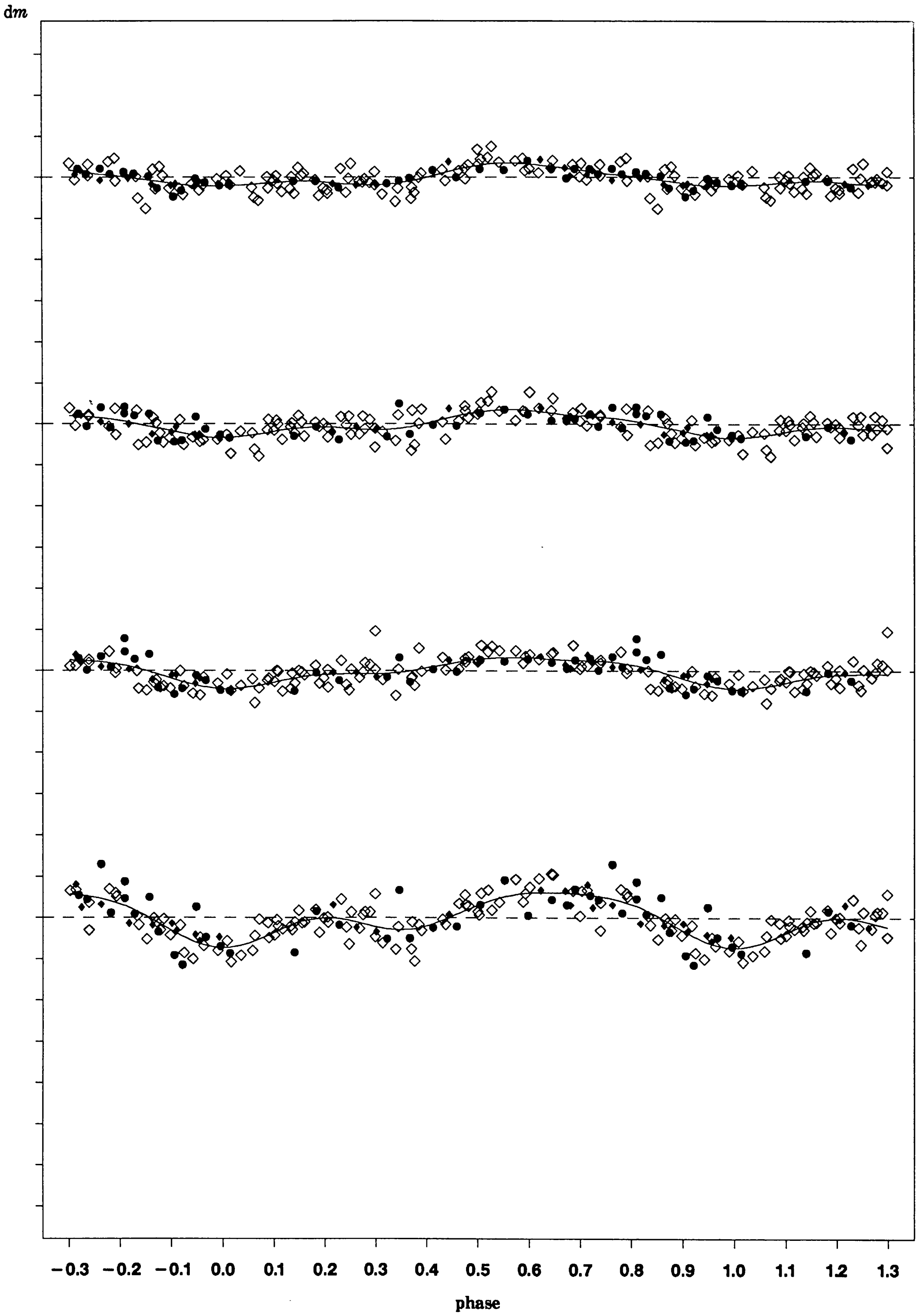

Fig. 1. Phase diagram of α Scl in y, b, v and u (from top) with the parameters listed in Table 4. Observations obtained during the JD interval 2 446 381 – 2 446 444 are not included (see Fig. 2). The curve is a multi-sine fit. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1994A&A...281...73M

Table 3. Stars analyzed

HD	HR	name	var. star	Rns	RA (2000)			Dec. (2000)			V	sp. type	comps.	N	JD interval
					(h)	(m)	(s)	(°)	(′)	(″)			(HD)		2 440 000+
5737	280	α Scl	(NSV 359)	1490	0	58	36	−29	21	27	4.3	B6 He wk	6178 4691	162	4861–7152
6178	293	σ Scl			1	2	26	−31	33	7	5.5	A2V	4691	163	4861–7152
54118	2683	27 G. Car	V386 Car	14860	7	4	18	−56	44	59	5.2	A0 Si	52622 57969	210	4578–7257
90044	4082	25 Sex	SS Sex	25890	10	23	26	−4	4	27	6.0	B9 SiCrSr	90882	160	4310–8656
103192	4552	β Hya	β Hya	29760	11	52	54	−33	54	29	4.7	B9 Si	101431	128	4310–7259
159376	6545	52 Oph	V2125 Oph	44850	17	35	18	−22	2	38	6.5	B9 Si	160915 156897	89	4025–7258
168733	6870	59 G. Sgr	V4050 Sgr	47280	18	22	53	−36	40	10	5.3	B8 TiSr	169679 167233	90	3342–7257
189832		GC27780	V4133 Sgr	52630	20	3	35	−38	51	3	6.9	A6 SrCrEu	189388 191889	142	3342–7097

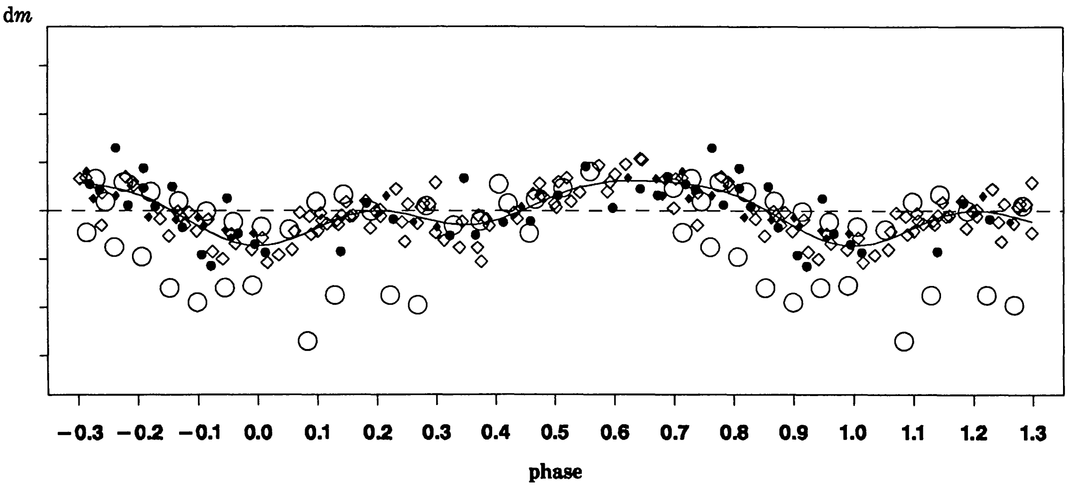

Fig. 2. Phase diagram of α Scl in u with the same parameters as for Table 2. Observations obtained during the JD interval 2 446 381 – 2 446 444 have been added as large open circles. Tick marks are separated by 0.01 mag

2 446 444. During this time interval, the star first appeared to be slightly too bright, then became systematically too faint by about $0\overset{\mathrm{m}}{.}02$ in u. Figure 2 shows those data superimposed on the u light-curve. Careful examination of all the LTPV data and of the reduction procedure showed that the phenomenon was real and could not be explained by some instrumental effect (the star is very bright, so the SAT photomultipliers are working in a non-linear regime). Interestingly, the Geneva data obtained at about the same epoch (JD 2 446 373 – 2 446 406) do not fit the $21\overset{\mathrm{d}}{.}652$ period, while data outside this time interval do. Although the star was not observed by the Geneva team when the Strömgren photometry showed it to be in the dimmer phases (JD 2 446 431 – 2 446 444), it can be concluded that α Scl displayed an unusual behavior at the end of 1985.

Several multi-periodic solutions could be found that reproduce the entire set of $uvby$ observations of α Scl with, beside the $21\overset{\mathrm{d}}{.}652$ period, additional values either very close to one day, or longer than one year. This looked like spurious artifacts of the time-distribution of the observations. Indeed, combining the Strömgren u data and the Geneva U allowed to reject all such solutions.

We investigated the behavior of the star during the critical two-month interval November-December 1985, in order to determine whether it could be explained by the onset of some periodic mechanism. Again, after prewhitening with the $21\overset{\mathrm{d}}{.}652$ period, the only possible solutions are found suspiciously close to one day, i.e., the sampling interval. Because of aliasing, slow variations would show up at such frequencies, but the possibility of aliasing had been reduced by varying the observation times. Hence, these data seem to point toward short-time variations. However, more intensive observations of similar events are needed to investigate the nature of the variations.

© European Southern Observatory • Provided by the NASA Astrophysics Data System

Table 4. Parameters of the least-squares fits for the programme stars. The error on each parameter is indicated in parentheses. σ is the scatter around the least-squares fit. r is the total range of the analytical light curve

α Scl $P = 21^{\mathrm{d}}.652$ $t_0 = 2\,447\,542.000$

	B_1	B_2	B_3	ϕ_1	ϕ_2	ϕ_3	σ	r
u	0.0050 (0.0013)	0.0029 (0.0013)	0.0014 (0.0013)	5.40 (0.27)	3.96 (0.45)	4.92 (0.77)	0.0032	0.0135
v	0.0032 (0.0008)	0.0009 (0.0007)	0.0007 (0.0007)	5.19 (0.22)	4.22 (0.84)	4.65 (0.77)	0.0023	0.0076
b	0.0028 (0.0006)	0.0008 (0.0006)	0.0008 (0.0006)	5.22 (0.20)	3.36 (0.59)	4.84 (0.57)	0.0023	0.0070
y	0.0024 (0.0008)	0.0010 (0.0007)	0.0005 (0.0007)	5.29 (0.31)	2.76 (0.69)	4.57 (1.09)	0.0020	0.0056

27 G. Car $P = 3^{\mathrm{d}}.27535$ $t_0 = 2\,445\,399.000$

	B_1	B_2	B_3	ϕ_1	ϕ_2	ϕ_3	σ	r
u	0.0139 (0.0009)	0.0059 (0.0009)	0.0004 (0.0009)	3.52 (0.06)	5.12 (0.13)	1.67 (1.88)	0.0052	0.0317
v	0.0166 (0.0005)	0.0011 (0.0005)	0.0009 (0.0005)	5.09 (0.03)	4.29 (0.41)	4.10 (0.54)	0.0041	0.0336
b	0.0143 (0.0004)	0.0081 (0.0004)	0.0007 (0.0004)	4.50 (0.02)	4.97 (0.04)	4.02 (0.56)	0.0040	0.0373
y	0.0077 (0.0005)	0.0057 (0.0005)	0.0001 (0.0005)	3.58 (0.06)	5.05 (0.08)	0.06 (–)	0.0033	0.0222

25 Sex $P = 4^{\mathrm{d}}.37900$ $t_0 = 2\,445\,659.000$

	B_1	B_2	B_3	ϕ_1	ϕ_2	ϕ_3	σ	r
u	0.0230 (0.0010)	0.0120 (0.0010)	0.0022 (0.0010)	4.30 (0.04)	5.04 (0.08)	5.00 (0.41)	0.0039	0.0602
v	0.0090 (0.0006)	0.0084 (0.0006)	0.0016 (0.0006)	5.98 (0.06)	5.09 (0.06)	4.38 (0.32)	0.0026	0.0316
b	0.0126 (0.0004)	0.0093 (0.0004)	0.0014 (0.0004)	6.14 (0.03)	5.16 (0.04)	4.76 (0.22)	0.0028	0.0376
y	0.0076 (0.0006)	0.0045 (0.0006)	0.0003 (0.0006)	6.23 (0.06)	5.25 (0.12)	5.11 (1.53)	0.0025	0.0200

β Hya $P = 2^{\mathrm{d}}.35666$ $t_0 = 2\,447\,062.000$

	B_1	B_2	ϕ_1	ϕ_2	σ	r
u	0.0317 (0.0011)	0.0079 (0.0011)	1.48 (0.03)	1.75 (0.11)	0.0037	0.0655
v	0.0200 (0.0006)	0.0041 (0.0006)	1.57 (0.02)	1.57 (0.11)	0.0024	0.0400
b	0.0194 (0.0005)	0.0042 (0.0005)	1.56 (0.02)	1.65 (0.09)	0.0027	0.0390
y	0.0145 (0.0006)	0.0034 (0.0006)	1.52 (0.03)	1.65 (0.14)	0.0023	0.0293

52 Oph $P = 9^{\mathrm{d}}.7383$ $t_0 = 2\,445\,939.000$

	B_1	B_2	B_3	ϕ_1	ϕ_2	ϕ_3	σ	r
u	0.0346 (0.0015)	0.0184 (0.0015)	0.0030 (0.0015)	4.76 (0.03)	4.66 (0.06)	4.70 (0.36)	0.0088	0.0818
v	0.0233 (0.0009)	0.0109 (0.0008)	0.0016 (0.0009)	4.80 (0.03)	4.67 (0.05)	5.06 (0.50)	0.0032	0.0534
b	0.0234 (0.0009)	0.0102 (0.0008)	0.0018 (0.0009)	4.85 (0.03)	4.70 (0.06)	4.99 (0.43)	0.0035	0.0532
y	0.0196 (0.0009)	0.0085 (0.0008)	0.0005 (0.0009)	4.86 (0.04)	4.72 (0.07)	5.18 (1.65)	0.0032	0.0445

59 G. Sgr $P = 6^{\mathrm{d}}.3540$ $t_0 = 2\,446\,726.000$

	B_1	B_2	ϕ_1	ϕ_2	σ	r
u	0.0118 (0.0022)	0.0006 (0.0022)	1.51 (0.13)	2.22 (–)	0.0046	0.0237
v	0.0041 (0.0012)	0.0015 (0.0012)	1.92 (0.27)	2.39 (0.84)	0.0042	0.0087
b	0.0050 (0.0009)	0.0017 (0.0009)	1.86 (0.16)	1.75 (0.44)	0.0044	0.0108
y	0.0056 (0.0012)	0.0016 (0.0012)	1.60 (0.16)	1.91 (0.68)	0.0038	0.0117

HD 189832 $P = 28^{\mathrm{d}}.530$ $t_0 = 2\,446\,777.000$

	B_1	B_2	ϕ_1	ϕ_2	σ	r
u	0.0015 (0.0013)	0.0011 (0.0013)	1.42 (0.71)	2.52 (1.20)	0.0047	0.0045
v	0.0042 (0.0008)	0.0079 (0.0007)	1.33 (0.15)	1.63 (0.07)	0.0036	0.0212
b	0.0021 (0.0006)	0.0019 (0.0005)	5.29 (0.27)	1.40 (0.24)	0.0039	0.0070
y	0.0034 (0.0008)	0.0023 (0.0007)	4.87 (0.18)	4.65 (0.24)	0.0034	0.0091

Table 5. Parameters of the least-squares fits for σ Scl, a comparison of α Scl

σ Scl $P = 2^{\mathrm{d}}.36975$ $t_0 = 2\,447\,735.000$

	B_1	B_2	ϕ_1	ϕ_2	σ	r
u	0.0019 (0.0016)	0.0007 (0.0016)	3.84 (0.88)	6.09 (1.87)	0.0041	0.0039
v	0.0003 (0.0009)	0.0002 (0.0009)	3.43 (2.74)	4.60 (–)	0.0032	0.0008
b	0.0009 (0.0007)	0.0004 (0.0007)	3.71 (0.80)	0.96 (1.58)	0.0030	0.0022
y	0.0000 (0.0009)	0.0001 (0.0009)	1.18 (–)	1.81 (–)	0.0028	0.0024

© European Southern Observatory • Provided by the NASA Astrophysics Data System

1994A&A...281...73M

One of the comparisons (HD 6178 = σ Scl) used in differential photometry proved to be variable, although with a very small amplitude. It is probably an Ap star. Several periods are possible. The most likely is

$$P = 2\overset{\mathrm{d}}{.}36975 \pm 0\overset{\mathrm{d}}{.}00020,$$

but $P = 1\overset{\mathrm{d}}{.}37675 \pm 0\overset{\mathrm{d}}{.}00010$ and aliases of these periods cannot be excluded. Table 5 gives the parameters of least-squares fits with the first period. The light curves are shown in Fig. 3. The extremely small amplitude led us to keep σ Scl as a comparison for α Scl, without even bothering to remove its variability. The noise due to this variability and affecting the α Scl differential data is totally negligible because (i) the amplitude is very small (see Table 5), (ii) the variability is halved by the use of a second comparison, and (iii) the periods of σ Scl and α Scl are not related. On the other hand the use of two comparisons instead of one is certainly an advantage since the overall noise in the differential data is decreased.

In spite of its small variations, it is worth noticing that σ Scl was listed by Rufener & Bartholdy (1982) in their list of suspected variables, on the basis of less than four measurements. However, the σ they quoted (0.062 mag in V) is very large and incompatible with what we found (the total amplitude in y is less than 0.003 mag). It is probable that some bad measurement(s) passed through the Geneva reduction procedure. Indeed, the most recent version of the Geneva catalogue (Rufener 1988) gives a much smaller σ, based on more observations, indicating that the star had been carefully monitored and that the wrong value(s) had been corrected or dropped.

4.2. 27 G. Car = Rns 4860

The discovery of the enhancement of Si lines in this star (HD type A0) has been made by Bidelman & Böhm (1955). Buscombe (1962) lists it as A0Si. Later, Bidelman (1971) confirmed the Si character, as did Houk & Cowley (1975) in the Michigan Catalogue (ApSi). The far UV spectrum is also peculiar as indicated by a very large δ_{1400} (Jamar et al. 1978).

From seven magnetic-field measurements, Borra & Landstreet (1975) deduced a period of $3\overset{\mathrm{d}}{.}2 \pm 0\overset{\mathrm{d}}{.}1$. Independently, Manfroid & Renson (1981) obtained $3\overset{\mathrm{d}}{.}275 \pm 0\overset{\mathrm{d}}{.}015$ from $uvby$ photometric measurements (Table 1, #2). Using these same observations, together with a few LTPV data, Manfroid & Mathys (1985; see also Mathys & Manfroid 1985) refined this value to $3\overset{\mathrm{d}}{.}2754 \pm 0\overset{\mathrm{d}}{.}0005$. Other values were still possible, separated by a very small integer multiple of 0.00091 d^{-1} in the frequency domain.

By then, the light variations of 27 G. Car seemed to be well established. However, there were some indication that a dip in the lightcurve might be present, similar to those observed in the lightcurves of TW Col (Renson & Manfroid 1992) and 46 Eri (Manfroid & Renson 1989). This led us to include this star in the LTPV programme, in order to accumulate a large number of observations.

Infrared observations by Catalano et al. (1991) show a very small variation: almost zero in J and K, and of the order of 0.03 mag in H with a probable double wave when phased with the above period. By using our $uvby$ mesurements (Table 1, #2), as well as the first batch of LTPV observations (Manfroid et al. 1991), and adding 10 measurements by themselves, Catalano & Leone (1993) proposed a period of $3\overset{\mathrm{d}}{.}275170 \pm 0\overset{\mathrm{d}}{.}000015$, within the error margin of Manfroid & Mathys (1985).

The study of the whole LTPV data set is now completed, including improved reductions of the data of the first catalogue. There is definitely no dip nor kink in the light curve. The period is established as

$$P = 3\overset{\mathrm{d}}{.}27535 \pm 0\overset{\mathrm{d}}{.}00010,$$

very close to the one proposed by Manfroid & Mathys (1985), but far – by more than ten times their error margin – from the value proposed by Catalano & Leone (1993). The $uvby$ lightcurves are shown in Fig. 4.

The abnormally large scatter displayed by the differential measurements appears to be due to the comparison stars, HD 52622 and HD 57969. The analysis of these comparison stars does not show evidence for periodic variations. Moreover, both of them appear to be equally unstable.

4.3. 25 Sex = Rns 25890

According to a Lick Observatory Report by Whitford (1960) the spectral peculiarity of this star, first suspected by Edwards, was confirmed by Bidelman & Svolopoulos. A spectral study by Bertaud & Floquet (1967) showed that Si and Cr are overabundant and that the K line is weak. In their catalogue of spectral classification for bright A stars, Cowley et al. (1969) gave the B9pSi(SrCr) type.

From 28 $uvby$ measurements made at ESO in 1980 (Table 1, #3), a photometric period of $4\overset{\mathrm{d}}{.}37 \pm 0\overset{\mathrm{d}}{.}04$ had been deduced (Manfroid & Renson 1983a). Adelman (1983) improved on this value in order to fit his spectrophotometric results, and he derived $4\overset{\mathrm{d}}{.}377$. Renson & Manfroid (1991) found $4\overset{\mathrm{d}}{.}3790 \pm 0\overset{\mathrm{d}}{.}0004$ by using LTPV data.

This star had been included in the LTPV programme because of the possible presence of a dip in the lightcurve. This proved to be inexistant, as can be seen from Fig. 5. A few deviant measurements in system #3 show the origin of this idea. The period is found to be

$$P = 4\overset{\mathrm{d}}{.}37900 \pm 0\overset{\mathrm{d}}{.}00004.$$

As can be seen from Table 4, 25 Sex is a star for which more than two terms are definitely needed in the Fourier series to accurately describe the light curve. 52 Oph presents a similar characteristic, while for other stars of our list the situation is less clear. This, and the accidents found in the light curves of some Ap stars, confirm that these objects often have rather complex variation patterns.

© European Southern Observatory • Provided by the NASA Astrophysics Data System

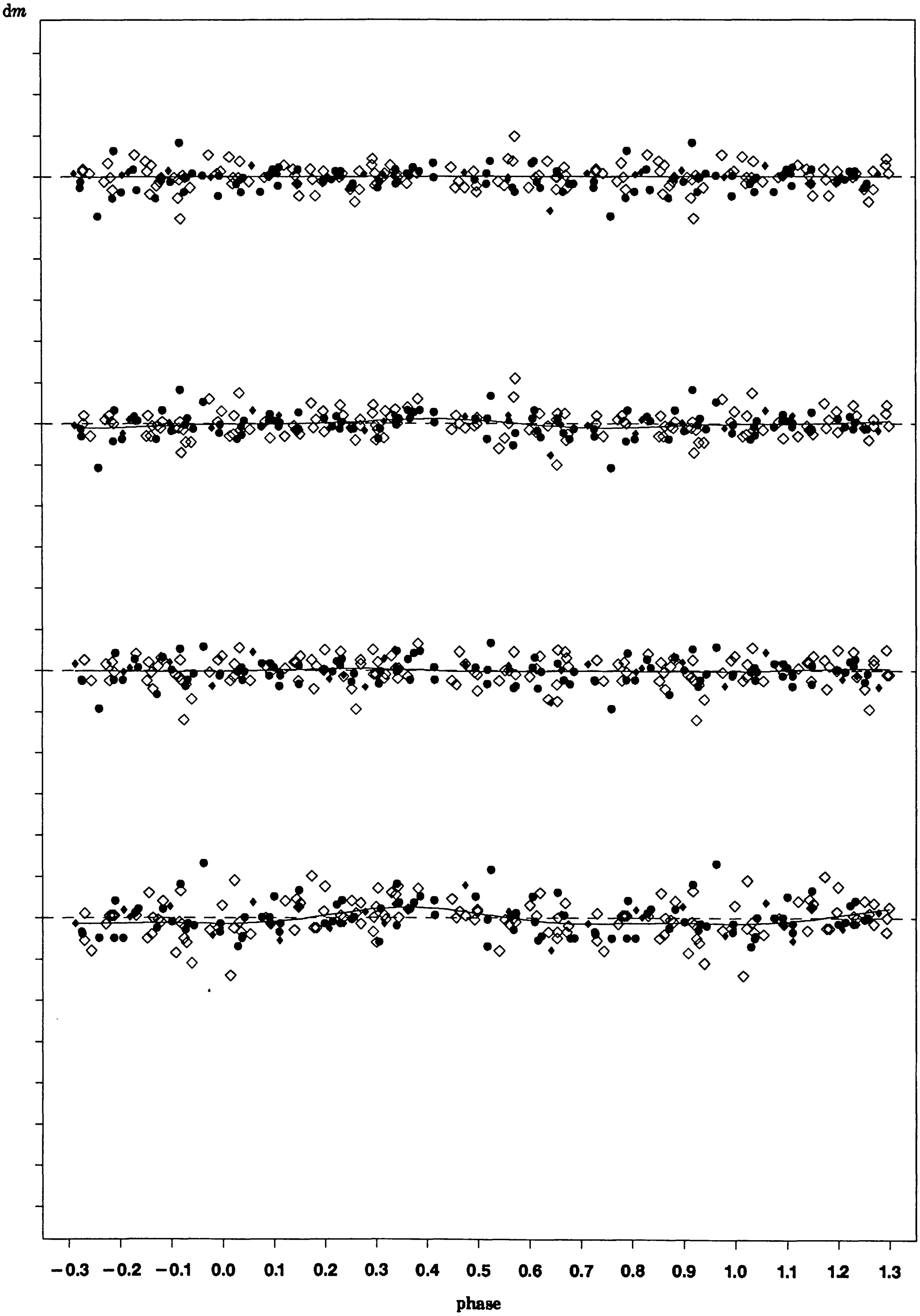

Fig. 3. Phase diagram of σ Scl in y, b, v and u (from top) with the parameters listed in Table 5. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

© European Southern Observatory • Provided by the NASA Astrophysics Data System

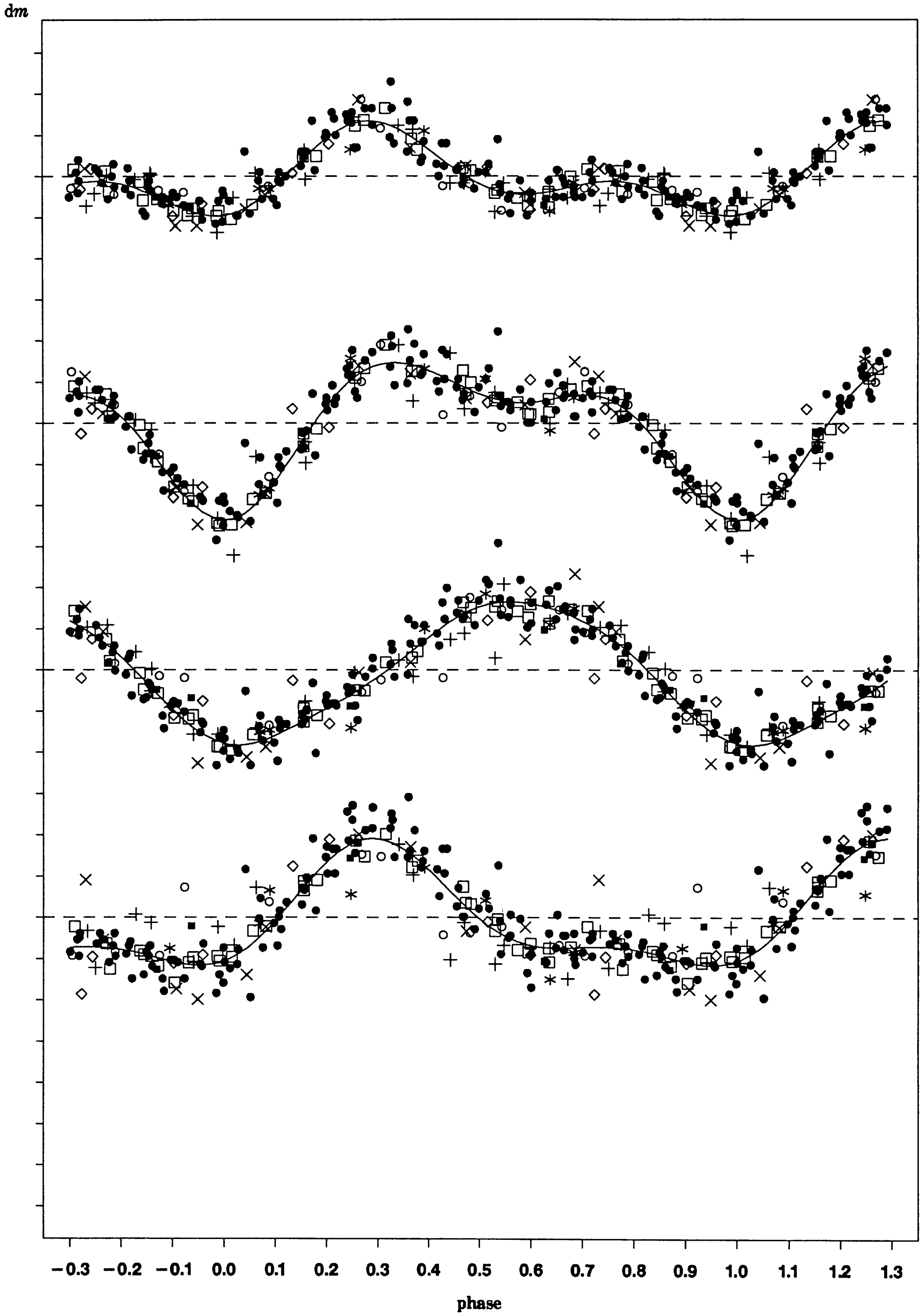

Fig. 4. Phase diagram of 27 G. Car in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

© European Southern Observatory • Provided by the NASA Astrophysics Data System

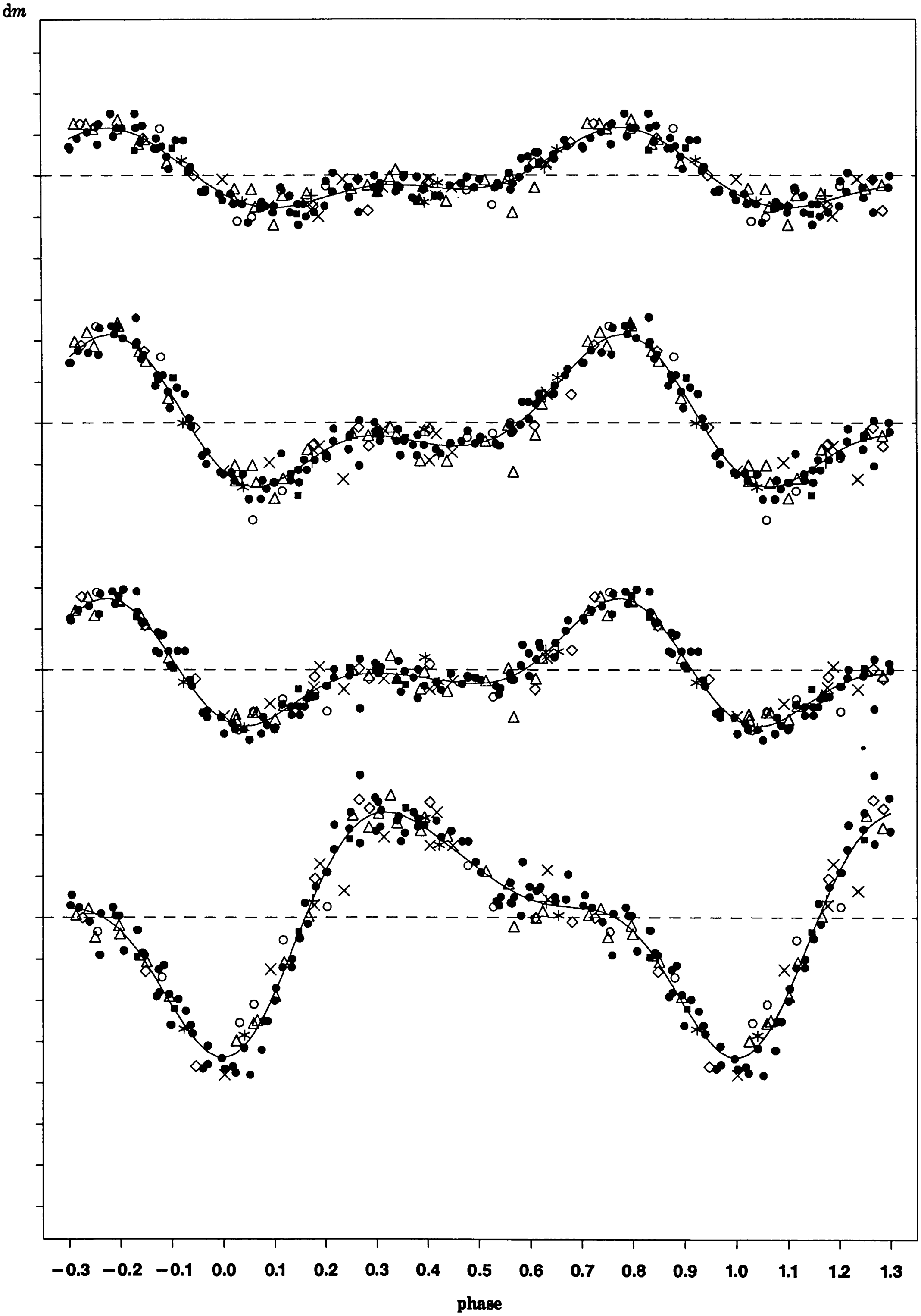

Fig. 5. Phase diagram of 25 Sex in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

4.4. β Hya = Rns 29760

The overabundance of Si was already reported in the Catalog of Bright Stars (Hoffleit 1964), with the spectral type A0Si. Molnar (1972) gave the type B9pIIISi. The star is listed as ApSi in the Michigan Catalogue (Houk 1982). Jamar et al. (1978) report a large value for δ_{1400}.

The photometric period of β Hya has been found to be about $2^{\mathrm{d}}.34$ or $2^{\mathrm{d}}.35$ by Manfroid & Renson (1983a) from 30 *uvby* measurements obtained at ESO in 1980 (Table 1, #3).

The star has a companion at about $1''$, fainter by about 0.8 mag. The actual range of variation is then underestimated by a factor of about 1.5 in V.

Preliminary indications that a dip might be present in the light curved proved to be false. The use of better reductions and of a larger data set yielded a smooth variation with a period

$$P = 2^{\mathrm{d}}.35666 \pm 0^{\mathrm{d}}.00002$$

(see Fig. 6). It is interesting to notice the effect of the incompatibility of various photometric systems in the u band. The amplitude given by system #7 (SAT telescope) is definitely larger than for the other systems. Small differences in the effective wavelength and in the profiles of the photometric bands can be critical for stars showing strongly wavelength-dependent variations. A similar, though less conspicuous, phenomenon is also present in the u light-curve of 27 G. Car (Fig. 4).

Allowing for this systematic effect of an instrumental nature, it is interesting to notice the small scatter around the mean light-curves (see Table 4 and Fig. 6). Obviously, the single comparison HD 101431 must be very stable, compared to those of, e.g., 27 G. Car.

Let us point out that the observations of β Hya were planned with a single comparison star which then got twice as many measurements as ordinary comparisons. This should be kept in mind when comparing with differential data where one of the two comparisons stars has to be discarded a posteriori (see, e.g., 52 Oph below).

4.5. 52 Oph = Rns 44850

The peculiar nature of the star was discovered by Cowley (1968) who gave a spectral type B8pSi-λ4200. The p-nature was confirmed by Bidelman (1971), but Bonsack (1974) found the "Si enhancement very slight". However, this enhancement has been confirmed by Klochkova et al. (1981): spectrum B9pSi-λ4200, with enhancement of other lines (Cr, Sr, Eu). The Si enhancement is also reported in the Michigan Catalogue (Houk 1988).

The photometric period of 52 Oph had been established by Renson & Manfroid (1980) as about $9^{\mathrm{d}}.75$, on the basis of 18 *uvby* measurements (Table 1, #10). North (1987) refined this value to $9^{\mathrm{d}}.74073 \pm 0^{\mathrm{d}}.00071$, using observations made in the Geneva photometric system. In this case also, the star was included in our programme because an anomaly was suspected in the light curve – anomaly which proved to be inexistant.

Our value of the period,

$$P = 9^{\mathrm{d}}.73830 \pm 0^{\mathrm{d}}.00010,$$

does not perfectly agree with the one proposed by North. The light curve is rather anharmonic since the Fourier series must be extended up to the third harmonic in order to fit the data in a satisfactory way. The total amplitude decreases from 0.082 mag in u down to 0.044 mag in y. In the indices, the amplitude is smaller, going from 0.011 mag in $b-y$ up to only 0.028 in c_1.

The rather high values of the scatter (see Fig. 7 and Table 4) are mainly due to a poor set of observations in system #6 (as can be seen on the light curve). Let us point out that these measurements were given an appropriately low weight in the chi-square analysis (Eq. 3).

4.6. 59 G. Sgr = Rns 47280

As for many other stars, Bidelman was first to note the peculiar nature of this one, but he apparently never published it. In his study of Ap stars Osawa (1965) gives the peculiarity λ4012. 59 G. Sgr is described as an "iron-titanium star" by Aller (in Whitford 1965, p. 614) because of large overabundances of Fe and mostly of Ti. The extensive study by Little & Aller (1970) reveals other overabundances, e.g., of Sr. Nevertheless, this star was not recognized as Bp in the Michigan Catalogue (Houk 1982), where it is quoted as a B7Ib/II giant – probably because the spectrum of this bright star was overexposed. The far-UV parameter δ_{1400} is large (Jamar et al. 1978).

A strong magnetic field has been found by Wood (1971) and its variations have been studied by Jones & Wolff (1974), who claimed a period of $14^{\mathrm{d}}.6$, though their published data are better represented by either $10^{\mathrm{d}}.13$ or $3^{\mathrm{d}}.795$.

The photometric period was found to be $6^{\mathrm{d}}.3 \pm 0^{\mathrm{d}}.3$ by Renson (1978b) on the basis of 14 *uvby* measurements made at ESO in 1977 (Table 1, #11). The value proposed by Manfroid & Renson (1992) is $6^{\mathrm{d}}.35395$. A noisy light curve, and the incompatibility between the magnetic and photometric periods, led us to ask for the inclusion of 59 G. Sgr in the LTPV programme.

According to Jones & Wolff (1974) this star is probably a spectroscopic binary. However, the amplitude of the velocity variation is very small.

One of the comparisons (HD 167233 = SAO 209922, V = 6.9) was found to be variable. A recent study by Jaschek & Jaschek (1992) lists it as B3Ve, with the H4 to H15 lines having central emissions. Large amplitude variations are seen, but well-defined periodicities could not be found from the data.

With only one comparison left, the data on 59 G. Sgr become unusually noisy. Our value for the the period is

$$P = 6^{\mathrm{d}}.3540 \pm 0^{\mathrm{d}}.0010.$$

The variations are smooth, with only a small contribution of the first overtone (see Fig. 8 and Table 4).

4.7. HD 189832 = Rns 52630

The peculiarity of this star was already noted in the HD catalogue (Cannon & Pickering 1923), since they listed its spectrum as being of type F0 or A5, resembling that of ξ Phe. Those authors also write that the strongest lines beside those of hydrogen

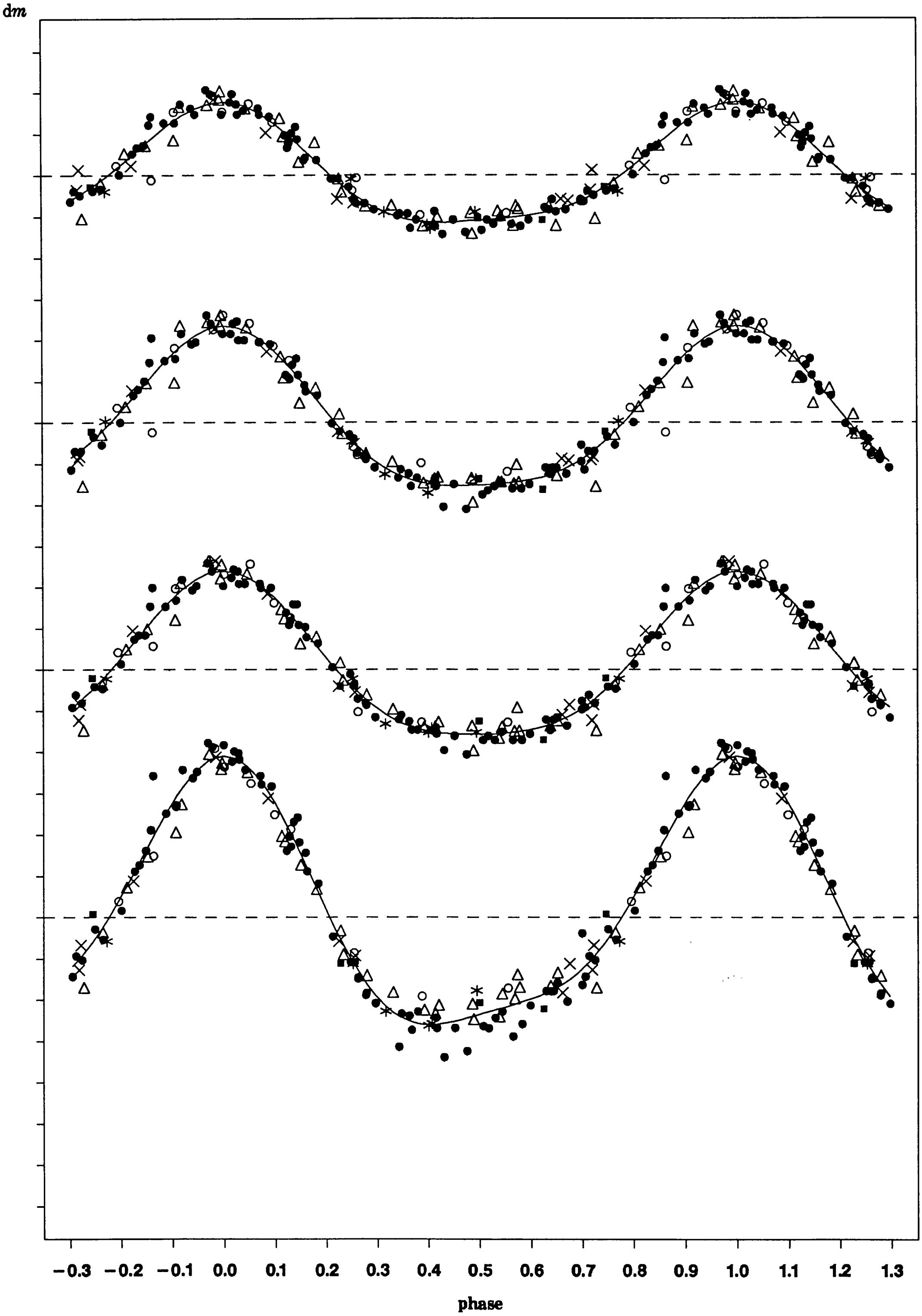

Fig. 6. Phase diagram of β Hya in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

© European Southern Observatory • Provided by the NASA Astrophysics Data System

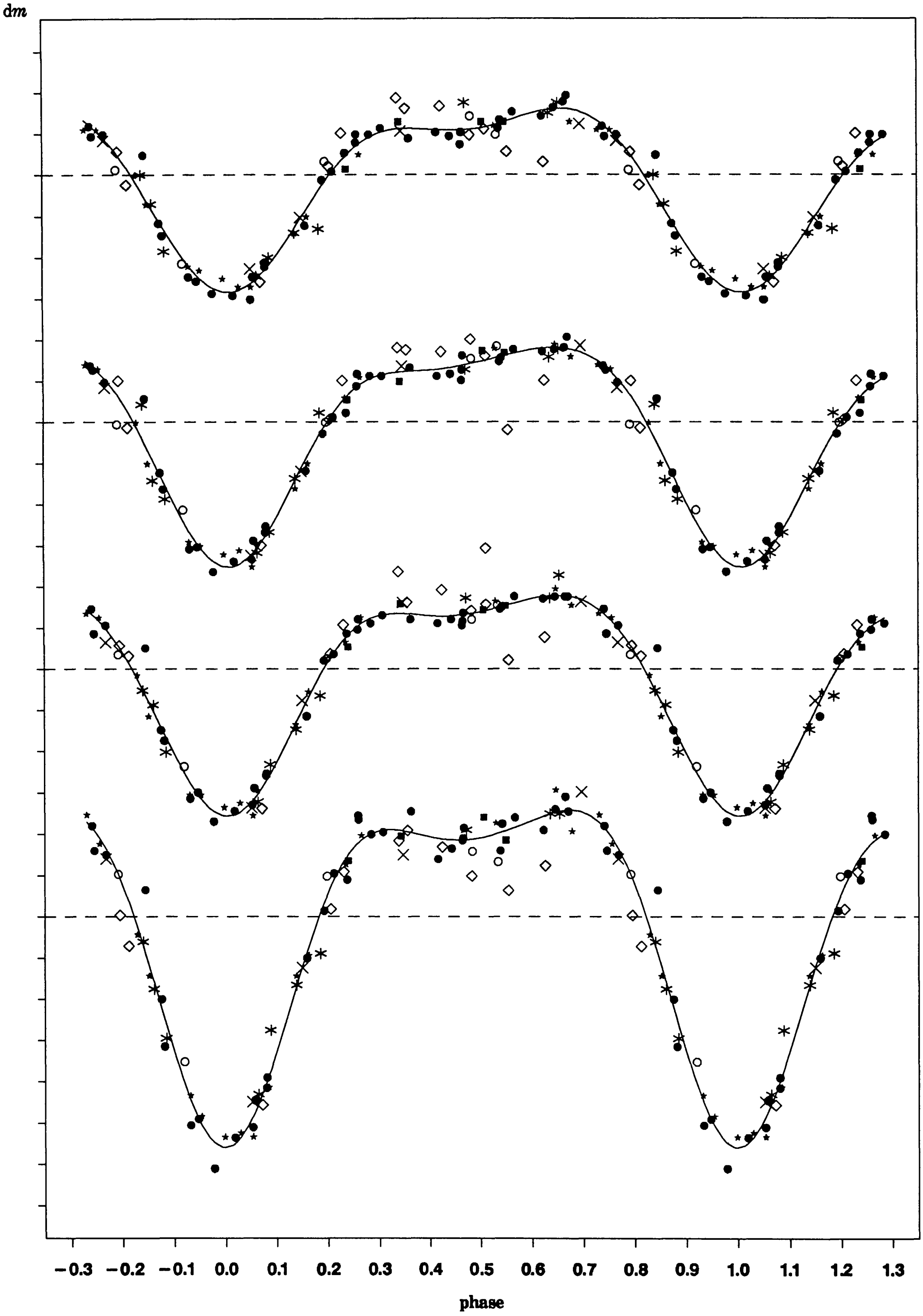

Fig. 7. Phase diagram of 52 Oph in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

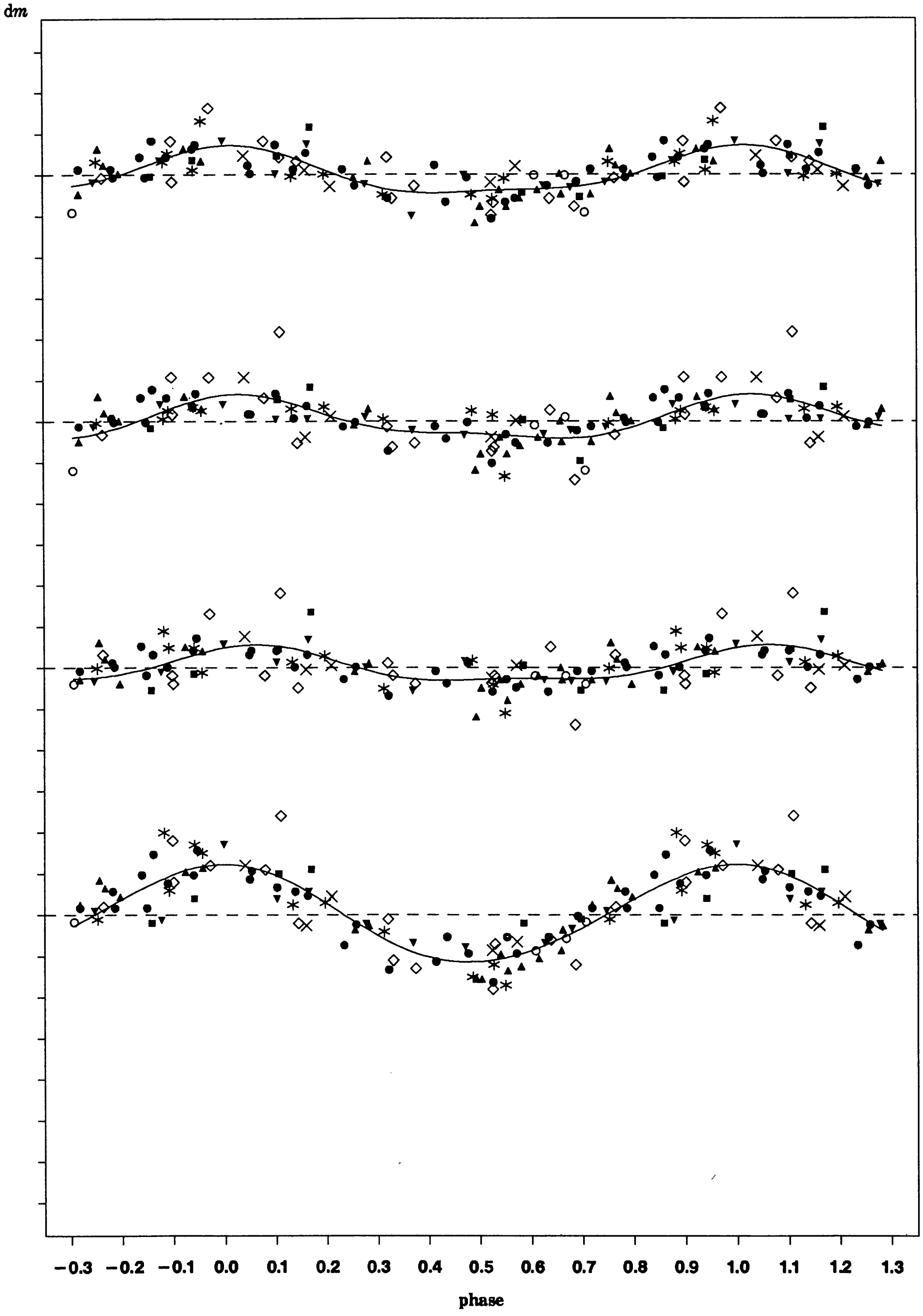

Fig. 8. Phase diagram of 59 G. Sgr in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

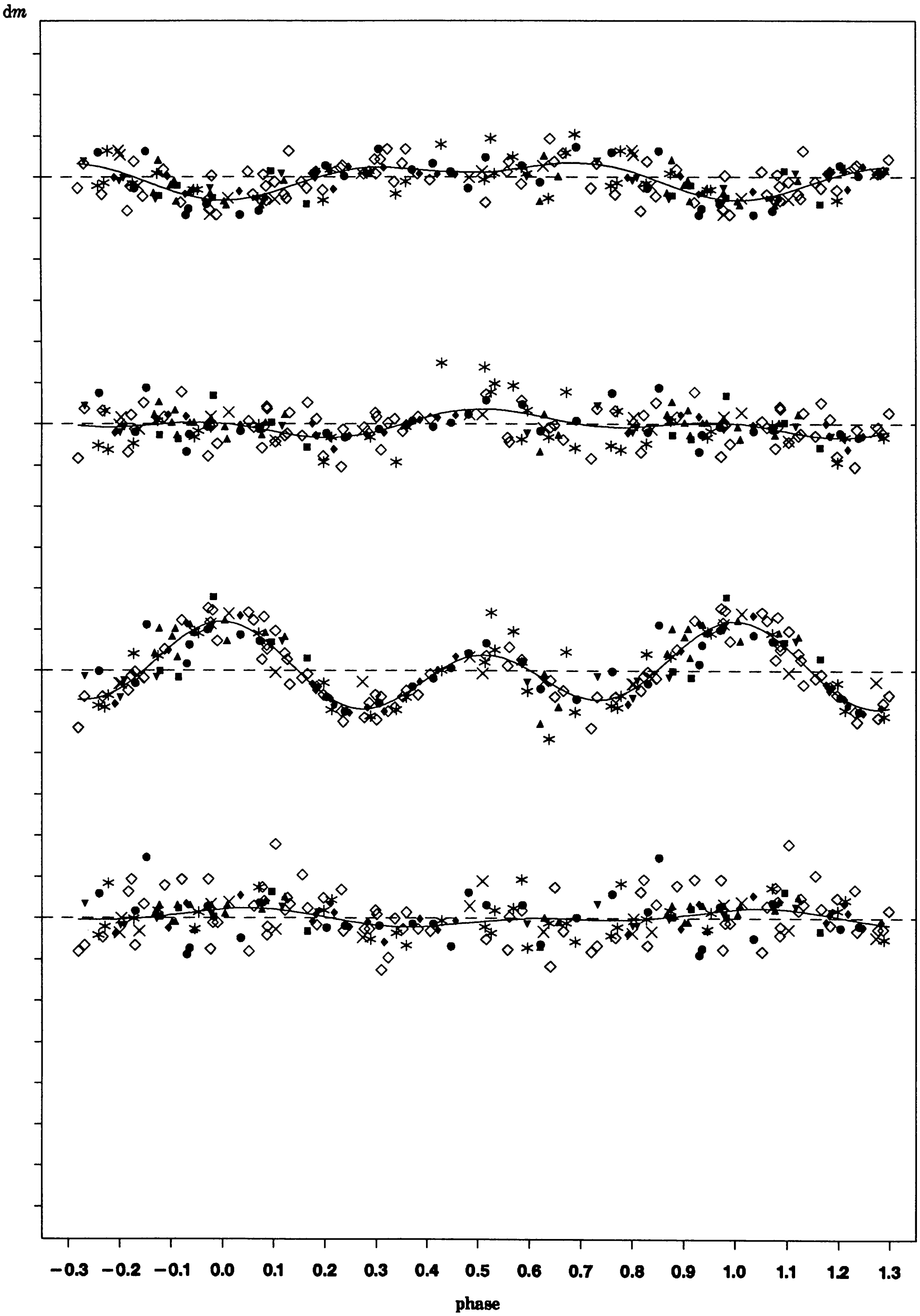

Fig. 9. Phase diagram of HD 189832 in y, b, v and u (from top) with the parameters listed in Table 4. Symbols representing the different photometric systems are shown in Table 2. Tick marks are separated by 0.01 mag

and calcium are $\lambda 4078$ (Sr), and $\lambda\lambda 4128/31$ (Si). In their list of southern peculiar stars Jaschek & Jaschek (1959) gave the spectral type F0pSrCrEu. According to Osawa (1965) the type is A3, A5:, and F0, respectively for the hydrogen spectrum, the K-line and the metallic lines, and exhibits the SrCrEu peculiarity. In the Michigan Catalogue (Houk 1982) the star is also given as ApSrCrEu.

Photometric *uvby* observations were made at ESO in 1977 (Table 1, #11), covering less than 15 days. From these data Renson (1978b) estimated that the period was somewhat longer than the duration of the observations, but "shorter than 30 days and probably around 20 days". Using data obtained during short periods in 1978 (Table 1, #12) and 1981 (Table 1, #13) Manfroid & Mathys (1985) proposed a value of $18\overset{\mathrm{d}}{.}89$, but with an unusually large number of equidistant frequencies. In order to solve the ambiguities, long-term observations were needed.

It now appears that the variations follow a double-wave pattern – at least in v were the amplitude is largest –, and this was the source of confusions in period searches. The period is found to be

$$P = 28\overset{\mathrm{d}}{.}530 \pm 0\overset{\mathrm{d}}{.}010$$

(see Fig. 9 and Table 4).

5. Conclusion

Long-term photometry proves to be a useful tool in the analysis of the photometric variations of some Ap stars. Accurate periods and detailed *uvby* light curves have been obtained for seven stars. Four of these stars were selected because they were suspected of displaying dips in their light curves. In each case this was not confirmed, and it seems that a smooth ligh curve is the rule in the Ap phenomenon – with very few exceptions.

The long series of data also allowed the detection of a rare episod of anomalous variations in the peculiar helium-weak star α Scl.

Acknowledgements. The authors are grateful to the observers of the LTPV programme, the names of whom appear in Table 1.

References

Abt H.A., 1979, ApJ, 230, 485
Adelman S.J., 1983, A&AS, 51, 511
Bertaud Ch., Floquet M., 1967, J. Obs., 50, 425
Bidelman W.P., 1971, private communication
Bidelman W.P., Böhm K.-H., 1955, PASP, 67, 179
Bond H.E., Perry Ch.L., Bidelman W.P., 1971, PASP, 83, 643
Bonsack W.K., 1974, PASP, 86, 408
Borra E.F., Landstreet J.D., 1975, PASP, 87, 961
Borra E.F., Landstreet J.D., Thomson I., 1983, ApJS, 53, 151
Brown D.N., Shore S.N., Barker P.K., Sonneborn G., 1984, in: The Future of Ultraviolet Astronomy Based on Six Years of IUE Research, Mead J.M., Chapman R.D., Kondo Y. (eds.). NASA CP-2238, p. 487
Buscombe W., 1962, Mt. Stromlo Mim., 4
Cannon A.J., Pickering E.C., 1923, Ann. Astr. Obs. Harvard Coll., 98
Catalano F.A., Kroll R., Leone F., 1991, A&A, 248, 179
Catalano F.A., Leone F., 1993, A&AS, 97, 501
Cousins A.W.J., Stoy R.H., 1963, Roy. Obs. Bull., 64
Cowley A.P., 1968, PASP, 80, 453
Cowley A.P., Cowley Ch., Jaschek M., Jaschek C., 1969, AJ, 74, 375
Deeming D.J., 1975, Ap&SS, 36, 137
Guthrie B.N.G., 1965, Pub. Roy. Obs. Edinburgh, 3, 264
Hoffleit D., 1964, Catalogue of Bright Stars, Yale Univ. Obs.
Houk N., 1982, Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 3., Univ. Mich.
Houk N., 1988, Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 4., Univ. Mich.
Houk N., Cowley A.P., 1975, Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 1., Univ. Mich.
Jamar C., Macau-Hercot D., Praderie F., 1978, A&A, 63, 155
Jaschek M., Jaschek C., 1959, PASP, 71, 48
Jaschek M., Jaschek C., 1966, Sympos. IAU. 24, Loden K., Loden L.O., Sinnerstad J. (eds.), pp. 30, 71, 48
Jaschek C., Jaschek M., 1992, A&AS, 95, 535
Jones J., Wolff S.C., 1974, PASP, 86, 67
Jugaku J., Sargent W.L.W., 1961, PASP, 73, 249
Klochkova V.G., Kopylov I.M., Kumaigorodskaia R.N., 1981, Pis'ma Astr. J., 7, 366
Kurtz D.W., Marang F., 1987, MN, 228, 141
Little S.J., Aller L.H., 1970, ApJS, 22, 157
Manfroid J., 1992, A&A, 260, 517
Manfroid J., Mathys G., 1985, A&AS, 59, 429
Manfroid J., Renson P., 1981, Inf. Bull. Variable Stars, 2004
Manfroid J., Renson P., 1983a, A&AS, 51, 267
Manfroid J., Renson P., 1983b, Inf. Bull. Variable Stars, 2311
Manfroid J., Renson P., 1989, A&A, 223, 187
Manfroid J., Renson P., 1992, cited in: Catalano F.A., Renson P., Leone F., Third Supplement to the Catalogue of Observed Periods of Ap Stars, A&AS, in press
Manfroid J., Sterken C., 1992, A&A, 258, 600
Manfroid J., Mathys G., Heck A., 1985, A&A, 144, 251
Manfroid J., Sterken C., Bruch A., Burger M., de Groot M. Duerbeck H.W., Duemmler R., Figer A., Hageman T., Hensberge H., Jorissen A., Madejsky R., Mandel H., Ott H.-A., Reitermann A., Schulte-Ladbeck R.E., Stahl O., Steenman H., vander Linden D., Zickgraf F.-J. 1991a, A&AS, 87, 481
Manfroid J., Sterken C., Bruch A., Burger M., de Groot, M. Duerbeck H.W., Duemmler R., Figer A., Hageman T., Hensberge H., Jorissen A., Madejsky R., Mandel H., Ott H.-A., Reitermann A., Schulte-Ladbeck R.E., Stahl O., Steenman H., vander Linden D., Zickgraf F.-J. 1991b, First Catalogue of Stars Measured in the Long-Term Photometry of Variables Project (1982–1986), ESO Scientific Report No.8
Manfroid J., Renson P., Catalano F.A., Leone F., Vogt N., Faundez M., 1991c, A&AS, 90, 19
Mathys G., Manfroid J., 1985, A&AS, 60, 17
Molnar M.R., 1972, ApJ, 175, 453
Norris J., 1971, ApJS, 23, 213
North P., 1984, A&AS, 55, 259
North P., 1987, A&AS, 69, 37
North P., 1993, private comm.
Osawa K., 1965, Ann. Tokyo Astr. Obs., 2nd ser., 9, 123
Pedersen H., 1979, A&AS, 35, 313
Renson P., 1978a, A&A, 63, 125
Renson P., 1978b, Inf. Bull. Variable Stars, 1391

Renson P., 1980, A&A, 92, 30

Renson P., 1991, Catalogue Général des Etoiles Ap et Am, Université de Liège

Renson P., Manfroid J., 1980, Inf. Bull. Variable Stars, 1755

Renson P., Manfroid J., 1991, cited in: Catalano F.A., Renson P., Leone F., Third Supplement to the Catalogue of Observed Periods of Ap Stars, A&AS, in press

Renson P., Manfroid J., 1992, A&A, 256, 104

Rufener F., 1988, Catalogue of Stars measured in the Geneva Observatory Photometric system, fourth edition, Obs. de Genève

Rufener F., Bartholdi P., 1982, A&AS, 48, 503

Shore S.N., Brown D.N., Sonneborn G., 1987, AJ, 94, 737

Shore S.N., Brown D.N., Sonneborn G., Landstreet J.D., Bohlender D.A., 1990, ApJ, 348, 242

Slettebak A., Brundage R.K., 1971, AJ, 76, 338

Sterken C., 1983, The Messenger, 33, 10

Sterken C., 1986, in: The Study of Variable Stars Using Small Telescopes, Percy J.R. (ed.). Cambridge University Press, p. 165

Sterken C., Manfroid J., 1992, Astronomical Photometry, a Guide. Kluwer Academic Publishers, Dordrecht

Sterken C., Manfroid J., Anton K., Barzewski A., Bibo E., Bruch A., Burger M., Duerbeck H.W, Duemmler R., Heck A., Hensberge H., Hiesgen M., Inklaar F., Jorissen A., Juettner A., Kinkel U., Liu Zongli, Mekkaden M.V., Ng Y.K., Niarchos P., Püttmann M., Szeifert T., Spiller F., van Dijk R., Vogt N., Wanders I. 1993, Second Catalogue of Stars Measured in the Long-Term Photometry of Variables Project (1986–1990), ESO Scientific Report, in press

Vilhu O., 1978, Inf. Bull. Variable Stars, 1378

Whitford A.E., 1960, AJ, 65, 531

Whitford A.E., 1965, AJ, 70, 609

Wood H.J., 1971, Bull. A.A.S., 3, 401

This article was processed by the author using Springer-Verlag $\TeX$ A&A macro package 1992.