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Starspot photometry with robotic telescopes. $UBV(RI)_C$ and *by* light curves of 47 active stars in 1996/97*

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Abstract. We present continuous multicolor photometry for 47 stars from October 1996 through June 1997. Altogether, 7073 $V(RI)_c$, UBV, and *by* data points, each the average of three individual readings, were acquired with three automatic photoelectric telescopes (APTs) at Fairborn Observatory in southern Arizona. Most of our targets are chromospherically active single and binary stars of spectral type G to K but there are also four pre-main-sequence objects and three pulsating stars in our sample. The light variability is generally due to rotational modulation of an asymmetrically spotted stellar surface and therefore precise rotational periods and their seasonal variations are determined from Fourier analysis. We also report on photometric variations of γ CrB (A0V) with a period of 0.44534 days. All data are available in numerical form.

Key words: stars: activity — stars: late-type — stars: rotation — binaries: spectroscopic — techniques: photometric

1. Introduction

Photometric monitoring of late-type stars has proven to be a powerful tool to discover cool starspots and to measure precise stellar rotation periods with, in some favorable cases, even differential rotation on the stellar surface (Hall 1972, 1994). The way the light and colors of a spotted star vary with time traces the evolution of its starspots. Time-series light and color curves can then be used to determine the approximate distribution of spots on the stellar surface, their temperature contrast, and even their appearance and disappearance marking the beginning and ending of a spot cycle similar to the Sun's 11-year cycle.

In the past decade several studies were presented that attempted to model long-term light-curve variations with an evolving spot distribution on the basis of one stellar rotation to the next. Much literature could be cited here but instead let us selflessly draw your attention to our own series of papers on "Time-series photometric spot modeling" and the many references therein. Paper I on the RS CVn binary VY Ari (Strassmeier & Bopp 1992) included a description of the modeling technique and were followed by Strassmeier et al. (1994a) on 15 years of photometry of HR 7275, Olàh et al. (1997) on 30 years of HK Lac and Olàh et al. (1999) on 10 years of V833 Tau. A particularly important spot parameter extractable from these data is the spot's lifetime and one result, still lively debatted, is that there is no linear decay law for starspots as there is for sunspots, i.e. the larger a sunspot the longer it lives (dA/dt = const; A being the spot area). Various physically similar stars in terms of rotation period and spectral type can host spots or spot groups with a wide range of lifetimes. For a set of four spotted RS CVn stars, Henry et al. (1995a) observed individual spot lifetimes between 0.5 years and over 6 years. The same range of lifetimes was found for the stars in our previous papers mentioned above. Maybe not surprising, the spotted star with the longest photoelectric history (RS CVn with 45 years of broad-band data) also shows the longest time scale: a cyclic change of the total spotted area with a period of 20 years (Rodonó et al. 1995). All these phenomena are suggestive of a significantly non-solar magnetic field topology and a dynamo process that might operate on many different timescales.

Clearly, continuous photometric monitoring for a long period in time is needed for conclusive analyses and *automatic photoelectric telescopes* (APTs) are ideally suited for such a task. In this paper, we present multicolor data from our two 0.75-m University of Vienna twin APTs

* All data are available from CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

(Strassmeier et al. 1997b) and the 0.25-m Phoenix-10 APT (Boyd et al. 1984) for 1996/97. Altogether, 47 program stars were observed in either *by*, UBV, or $V(RI)_C$. Some special cases were targeted in all of these bandpasses but with varying time and phase coverage on the individual telescopes. Others had been observed only briefly and their aim was mostly to support spectroscopic observations for Doppler imaging with large telescopes (see, e.g., Rice & Strassmeier 1998). Table 1 presents a summary of the program stars and their commonly known stellar parameters. A period analysis for all stars from each individual telescope gives a homogeneous set of stellar rotation periods and the associated rotational light variations.

2. Instrumentation and data quality

All three telescopes are located at Fairborn Observatory near Washington Camp in southern Arizona and operate fully automatically (see http:// 24.1.225.36/ fairborn.html for a description of the observatory).

2.1. The two 0.75-m APTs "Wolfgang" and "Amadeus"

The Wolfgang APT is optimized for blue wavelengths with an EMI-9124QB photomultiplier and Strömgren *by* filters while Amadeus is optimized for red wavelengths with an EMI-9828 tube and Johnson-Cousins $V(RI_C)$ filters (for details we refer to Strassmeier et al. 1997b). All measurements were made differentially between the variable and a comparison star (the latter is sometimes referred to as the "Comp" star). A check star is used to verify the stability of the comparison star (we sometimes refer to it as the "Check" star). Stars brighter than $\approx 5^m$ were measured with a neutral-density filter in front of the spectral filter. Integration time was usually set to 10 s except for stars fainter than $8-9^m$ where $20-30$ s for the broad-band filters and $30-60$ s for the intermediate-band filters were used. The data reduction was based on nightly extinction coefficients obtained from a set of standard stars or, for the nights when an insufficient number of standards was observed (less than 20), an average of the previous three good nights was adopted. Otherwise, the procedures were the same as described in Strassmeier et al. (1997a).

After the obviously deviant data points due to misidentifications and clouds were eliminated, we computed external uncertainties, σ_{ext}, for all check-minus-comparison magnitudes. Such uncertainties allow an examination of the long-term data quality expected for the variable-minus-comparison data. The mean external standard deviation of a "nightly mean" from a yearly mean was for Wolfgang 4 millimag in b and y, and for Amadeus 6, 8, and 10 millimag in V, R, and I, respectively. The mean internal standard deviations from three readings of the variable and four readings of the comparison star were less than 2 millimag for Wolfgang and approximately 4 millimag for Amadeus. Between May and June 1997, the Amadeus APT had gotten repeatedly out of focus and the internal standard deviations raised to $7-8$ millimag in V during this time.

2.2. The Phoenix-10 0.25 m APT

The Phoenix-10 APT is now located at the same site in Washington Camp as Wolfgang-Amadeus and thus follows the same weather and extinction pattern. It is already in routine operation since 1983 and is managed by Mike Seeds at Franklin & Marshall College as a multi-user telescope (see "Phoenix-10 Newsletter" and Seeds 1995). Strassmeier & Hall (1988a) examined its data quality from its first four years of operation and found external uncertainties of 10, 20, and 28 millimag in V, B, and U, respectively. For the stars in this paper, integration times were set to 10 s for all targets. More recently, Henry (1995) compared the long-term external precision of the Phoenix-10 APT with APTs of larger aperture (the Vanderbilt/Tennessee State 0.4 m and the Tennessee-State 0.8 m) and verified the telescope's long-term stability. A further comparison was made with Wolfgang and Amadeus as well as with the University of Catania 0.8 m APT on Mt Etna (Strassmeier et al. 1997a). All relative zeropoints in the V bandpass agreed to within their formal errors. In order to eliminate datapoints grossly in error, we applied a statistical procedure that excluded all data with an internal standard deviation greater than 20 millimag in V.

3. Results

Table 1 lists the program stars and summarizes their most relevant stellar properties taken either from the recent literature or from the second edition of the catalog of Chromospherically Active Binary Stars (CABS, Strassmeier et al. 1993) if appropriate. Table 2 identifies the comparison and the check stars, the observing interval, whether a neutral density filter was needed or not, the useable number of differential data points – each the mean of three readings on the variable and the comparison –, and which telescope was used.

3.1. Seasonal light curves

The individual panels in Fig. 1 through Fig. 45 present the photometric data in one bandpass (usually V or y), the periodogram from these data, and the phased seasonal light curve from the best-fit period. We emphasize that the sometimes abnormally large scatter in the phase plots is almost exclusively due to intrinsic spot changes and not due to instrumental scatter.

Table 1. Program stars

Star	V (mag)	Spectral type	Binary? (SB/S)	P_{orb} (days)	P_{phtm} (days)	$v \sin i$ ($km\,s^{-1}$)	Radius ($R_\odot$)	Variable type
HR 5B (V640 Cas)	6.6	G8V	SB1	39.5	n.det.	4.7	...	solar-type SB
SAO 91772 (LN Peg)	8.6	G8V	SB2	1.844	1.851	23	≥0.84	RS CVn
HD 4502 (ζ And)	4.1	K1IIIa	SB1	17.769	17.637	41	≥14.3	RS CVn + ell.
HD 12545 (XX Tri)	8.1	K0III	SB1	23.98	23.87	18.2	≥8.6	RS CVn
HD 17433 (VY Ari)	6.8	K3-4IV	SB1	13.198	16.23	10	≥3.2	RS CVn
HD 22468 (V711 Tau)	5.7	K1IV	SB2	2.8377	2.837	40	3.9	RS CVn
HD 26337 (EI Eri)	7.0	G5IV	SB1	1.947	1.913	50	≥1.9	RS CVn
HD 283518 (V410 Tau)	11.2	K4	S	...	1.872	77	3.0	WTTS
HR 1362 (EK Eri)	6.3	G8III-IV	S	...	(306.9)	1.5	9	single giant
HD 283571 (RY Tau)	10	F8V	S	...	n.det.	49	...	CTTS
HD 283572 (V987 Tau)	9.3	G5	S	...	1.529	78	≥2.3	WTTS
HD 283750 (V833 Tau)	8.2	K5V	SB1	1.788	1.806	6.3	≥0.22	BY Dra
HD 282624 (SU Aur)	8.9	G2	S	...	n.det.	66	≥3.9	CTTS
HD 31964 (ϵ Aur)	3.0	F0Ia	ECL	27yr	n.det.	...	...	puls. supergiant
HD 31993 (V1192 Ori)	7.5	K2III	S	...	26.7	33	≥17.4	single giant
HD 33798 (V390 Aur)	7.0	G8III	S	...	9.69	33	≥6.3	single giant
HD 291095 (V1355 Ori)	8.7	K1IV	SB1	?	3.87	46	≥3.5	RS CVn-type
HD 43989 (V1358 Ori)	8.5	G0IV	S	...	(3.2:)	42	≥3.2	RS CVn-type
HD 51066 (CM Cam)	7.2	G8III	SB1	3770.	16.0	47	17.4	eff. single giant
HD 62044 (σ Gem)	4.3	K1III	SB1	19.604	19.615	27	12	RS CVn
HD 81410 (IL Hya)	7.5	K1III	SB2	12.905	12.674	26.5	8.1	RS CVn
HD 82443 (DX Leo)	7.0	K0V	S	...	5.432	5	≥0.54	BY Dra
HD 82558 (LQ Hya)	7.8	K2V	S	...	1.60	28	0.94	BY Dra
HD 98230 (ξ UMa B)	3.8	G5V	SB1	3.980	n.det.	2.8	...	solar-type SB
HD 106225 (HU Vir)	8.6	K0III-IV	SB1	10.39	10.66	27	≥5.7	RS CVn
HD 111395 (HR 4864)	6.3	G5V	S	...	15.80	2.9	≥0.90	solar type
HD 111812 (31 Com)	4.9	G0III	S	...	6.96:	57	≥7.8:	single giant
HD 112313 (IN Com)	8.0	G5III-IV	SB1	?	5.90	67	≥7.8	RS CVn
HD 112989 (37 Com)	4.9	G9III	S	...	n.det.	4	...	single giant
HD 117555 (FK Com)	8.1	G2III	S	...	2.4067	160	≥7.3	FK Comae
HD 129333 (EK Dra)	7.5	G0-1V	S	...	2.598	17.5	0.92	solar type
HD 136901 (UV CrB)	7.2	K2III	SB1	18.665	18.657	42	≥15.5	RS CVn + ell.
BD-08°3999 (UZ Lib)	9.3	K0III	SB1	4.77	4.75	67	≥6.3	RS CVn
HD 139006 (α CrB)	2.2	A0V+G5V	SB	17.4	n.det.	≤14	...	eclipsing
HD 140436 (γ CrB)	3.8	A0V	VB	91yr	0.44534	100	≥0.88	Maia type
HD 141714 (δ CrB)	4.6	G3.5III-IV	S	...	57	5	≥5.8	single giant
HD 152178 (V2253 Oph)	8.2	K0III	SB1	314.	22.07	28.8	≥12.6	RS CVn
HD 171488 (V889 Her)	7.3	G0V	S	...	1.337	33	≥0.87	solar type
HD 199178 (V1794 Cyg)	7.2	G5III-IV	S	...	3.342	67	≥4.4	FK Comae
HD 208472 (V2075 Cyg)	7.3	G8III	SB1	22.6	22.42	19.7	≥8.7	RS CVn
HD 209813 (HK Lac)	6.9	K0III	SB1	24.428	24.15	20	≥9.5	RS CVn
HR 9024 (OU And)	5.9	G1III	S	...	24.2	20	≥9.6	single giant
HD 216489 (IM Peg)	5.6	K2II-III	SB1	24.65	24.45	28.2	≥13.6	RS CVn
HD 216672 (HR Peg)	6.3	S	S	...	irr.	...	...	semiregular
HD 218153 (KU Peg)	7.6	G8II-III	SB1	1411.	25.9	29	≥14.8	RS CVn
HD 224085 (II Peg)	7.4	K2-3IV	SB1	6.724	6.725	23.1	≥3.0	RS CVn

3.2. Photometric periods

Table 1 includes the results from our period analysis. We applied a menu-driven program that performs a multiple frequency search through Fourier transforms with a non-linear least-squares minimization of the residuals (Sperl 1998). The Fourier search range included a large number of frequencies up to the Nyquist frequency with a frequency spacing optimized for each individual data set. In most situations the frequency with the highest amplitude was adopted but in some cases, e.g. when the light curve appeared double humped, $f = 2\ f_{highest}$ was used. The best

Table 2. Identification of comp and check stars and number, n, of differential observations

Variable	Comparison	Check	Time range 2 400 000+	$n_{\rm Wolfgang}$ by	$n_{\rm Amadeus}$ VRI	$n_{\rm Phoenix}$ UBV
HR 5B (V640 Cas)[1]	HD 663	HD 224784	50395 – 50635	52	...	...
SAO 91772 (LN Peg)	SAO 91775	HD 977	50409 – 50635	35	...	...
HD 4502 (ζ And)[1]	HD 5516	HD 3690	50395 – 50635	105	...	...
HD 12545 (XX Tri)	HD 12478	SAO 55178	50395 – 50500	...	116	53
HD 17433 (VY Ari)	HD 17572	HD 17361	50386 – 50516	...	...	55
HD 22468 (V711 Tau)[1]	HD 22484	HD 22796	50395 – 50490	132	109	...
HD 26337 (EI Eri)	HD 25852	HD 26584	50395 – 50529	...	128	...
HD 283518 (V410 Tau)	HD 27159	HD 27570	50395 – 50525	...	125	...
HR 1362 (EK Eri)[1]	HD 27197	HD 26409	50395 – 50500	...	122	...
HD 283571 (RY Tau)	HD 27159	HD 27570	50395 – 50529	...	128	...
HD 283572 (V987 Tau)	HD 27570	HD 28447	50395 – 50532	179	115	...
HD 283750 (V833 Tau)	HD 283749	HD 29169	50395 – 50521	...	127	...
HD 282624 (SU Aur)	HD 31565	HD 31305	50395 – 50534	...	147	...
HD 31964 (ϵ Aur)	HD 33167	...	50395 – 50426	100	...	...
HD 31993 (V1192 Ori)	HD 32191	HD 32073	50395 – 50536	...	140	...
HD 33798 (V390 Aur)	HD 34248	HD 33443	50396 – 50540	...	26	...
HD 291095 (V1355 Ori)	HD 41433	HD 40347	50492 – 50551	36	64	...
HD 43989 (V1358 Ori)	HD 44517	HD 44019	50492 – 50554	34	39	...
HD 51066 (CM Cam)	HD 48840	HD 45947	50486 – 50562	...	103	...
HD 62044 (σ Gem)[1]	HD 60318	HD 58207	50395 – 50536	471	...	...
HD 81410 (IL Hya)	HD 81904	HD 80991	50395 – 50594	...	235	...
HD 82443 (DX Leo)	HD 83098	HD 83821	50392 – 50604	...	...	161
HD 82558 (LQ Hya)	HD 82477	HD 82508	50395 – 50593	...	202	145
HD 98230 (ξ UMa)[1]	HD 98262	HD 94600	50408 – 50614	244	...	...
HD 106225 (HU Vir)	HD 106270	HD 106332	50410 – 50633	...	191	56
HD 111395 (HR 4864)[1]	HD 111469	HD 111812	50429 – 50636	...	257	...
HD 111812 (31 Com)	HD 111469	HD 111395	50401 – 50636	...	...	169
HD 112313 (IN Com)	HD 112299	HD 112706	50419 – 50636	168	226	...
HD 112989 (37 Com)[1]	HD 111469	HD 111812	50415 – 50635	...	274	...
HD 117555 (FK Com)	HD 117567	HD 117876	50421 – 50632	132	...	...
HD 129333 (EK Dra)	HD 129390	HD 129798	50437 – 50576	...	183	143
HD 136901 (UV CrB)	HD 136643	HD 136655	50492 – 50636	90	146	...
BD-08°3999 (UZ Lib)	SAO 140587	SAO 140589	50451 – 50635	...	139	...
HD 139006 (α CrB)[2]	HD 140436[3]	HD 141714[4]	50458 – 50568	267	...	...
HD 152178 (V2253 Oph)	HD 152501	HD 151179	50468 – 50636	...	120	...
HD 171488 (V889 Her)	HD 171286	HD 170829	50395 – 50636	93	179	...
HD 199178 (V1794 Cyg)	HD 199956	HD 199870	50395 – 50635	...	67	...
HD 208472 (V2075 Cyg)	HD 208341	HD 208916	50395 – 50635	...	96	...
HD 209813 (HK Lac)	HD 210731	HD 208728	50395 – 50635	...	86	...
HR 9024 (OU And)[1]	HD 223848	HD 222451	50395 – 50635	...	89	...
HD 216489 (IM Peg)	HD 216635	HD 216672[5]	50395 – 50635	...	73	...
HD 218153 (KU Peg)	HD 218610	SAO 91066	50395 – 50635	...	75	...
HD 224085 (II Peg)	HD 223332	HD 224895	50395 – 50635	...	26	...

[1] With $1\overset{\rm m}{.}25$ neutral-density filter for Var, Comp, and Check.
[2] With $3\overset{\rm m}{.}75$ neutral-density filter for Var and Comp, and $2\overset{\rm m}{.}5$ for Check.
[3] This is the variable star γ CrB (see discussion).
[4] This is the variable star δ CrB (see discussion).
[5] This is the variable star HR Peg = HR 8714 (see discussion).

fits are determined by minimizing the squares of the residuals between trial fits and measurements, and is done with program `curfit` (Bevington 1969). The function that is fit to the data is

$$m(t) = A_0 + \sum_{i=1}^{7} A_i \sin(2\pi f_i + 2\pi\phi_i) \qquad (1)$$

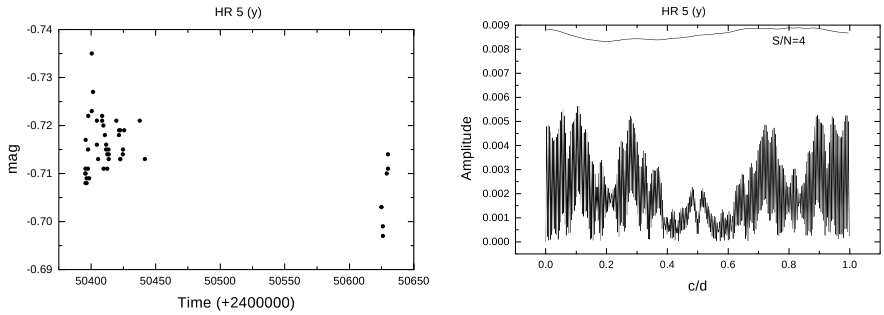

Fig. 1. The y-light variations of HR 5B in 1996/97 (left panel). The right panel is the periodogram showing the adopted significance level at a signal-to-noise ratio of 4 according to the criteria of Breger et al. (1993). No clear period was found for HR 5. For individual comments and discussions, see Sect. 4

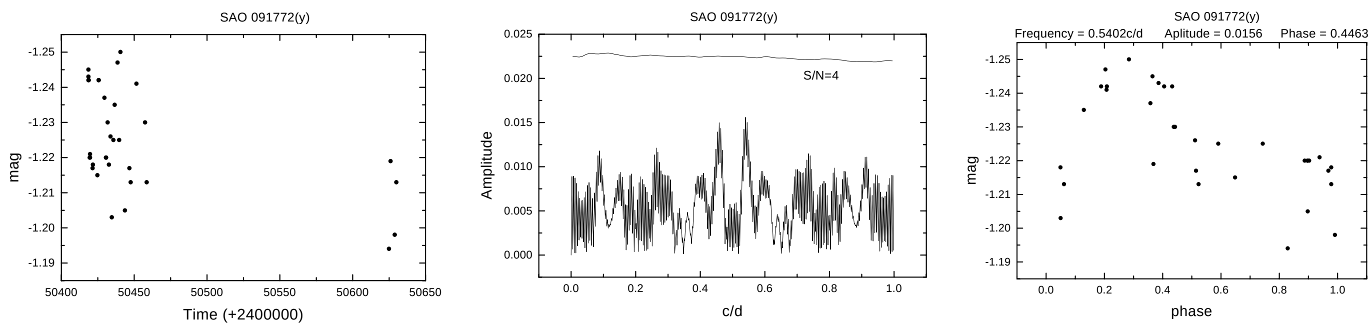

Fig. 2. LN Peg (=SAO 91772). The right panel shows the phased light curve from the best-fit period listed in Table 1. The corresponding frequency peak is indicated in the header of the plot along with the Fourier (half) amplitude and the phase shift from time $T_0 = 0$. Note that the phase plots show the combined data from the entire observing season and its scatter is usually due to intrinsic amplitude changes

where $m(t)$ is the predicted magnitude, A_0 is the magnitude zeropoint and is subtracted prior to minimization, A_i are the amplitudes for each frequency (half of the peak-to-peak light curve amplitudes), f_i are the frequencies, and ϕ_i is the phase given in units from 0 to 1. Note that $i = 7$ is the maximum number of simultaneous frequencies for the least-squares minimization. In our case, a single frequency ($i = 1$) was sufficient for all data sets and is physically plausible.

To judge the significance of certain frequency peaks we overplot a running mean of the frequency distribution for a signal-to-noise (S/N) ratio of 4:1 which was found empirically by Breger et al. (1993). From numerical simulations with varying amounts of white noise, it was shown by Kuschnig et al. (1997) that frequency peaks with $S/N \geq 4.0$ suggest a 99.9% probability for a real period. Individual errors are estimated from the width of the frequency peak at $\chi^2_{\rm min} + \chi^2_{\rm min}/(n-m)$ where n is the number of data points and m the number of parameters ($n - m$ is then the number of the degrees of freedom; $m = 4$ in our case). For details we refer to Bevington (1969).

The periods designated $P_{\rm phtm}$ in Table 1 are the average photometric periods computed from the individual bandpasses and are always given up to the last significant digit. The light curves in the figures are phased with these periods unless otherwise noted. The corresponding zero point in time is $T_0 = 0$ for all light curves. The phase shift of the light-curve maximum with respect to T_0 is indicated in the upper right corner of each phase-curve panel in Figs. 1–45. A slight shift between light curves for the same star but from different telescopes is due to slight differences in the separately obtained periods.

Table 1 also contains a column for the stellar radius that is computed from the value of $v \sin i$, the latter taken from the literature, and our photometric period.

4. Discussion of individual stars

The following discussion is intended to highlight particularly interesting features in the light-curve behavior of individual stars in 1996/97 but is not supposed to be a summary of all the relevant literature data. For the more fundamental parameters of the stars in common with our previous APT paper (Strassmeier et al. 1997a), we refer the reader to the discussion in that paper. For a complete listing of all available literature on a particular star we recommend to consult the SIMBAD data base at CDS Strasbourg.

HD 123 (HR 5B, V640 Cas). This triple system consists of a visual binary with components A and B, where B is additionally a spectroscopic binary. The A component

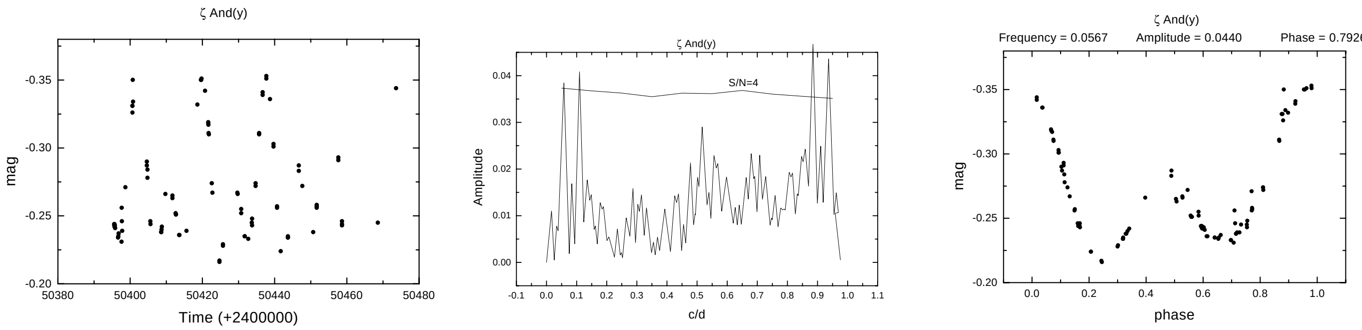

Fig. 3. As in Fig. 1 but for ζ And. The main cause for the light curve variability is the ellipticity effect

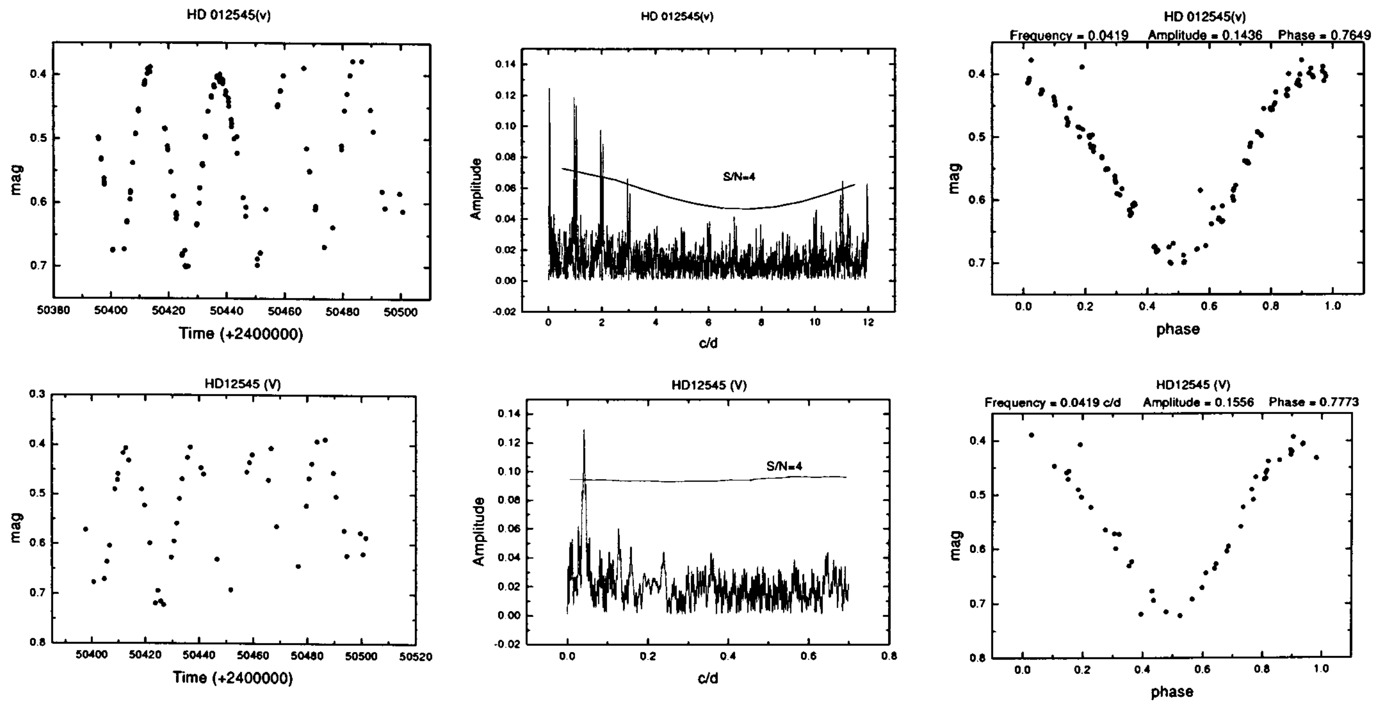

Fig. 4. As in Fig. 1 but for HD 12545. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Phoenix-10 UBV data

and one of the B components are visible in the optical spectrum. A subset of the photometric data in this paper was previously analysed by Weber & Strassmeier (1998a) along with radial velocities from high-resolution spectra. They found a weakly significant photometric period of 1.127 days and a radial-velocity period of 1.026 days which seemed to agree with the previously claimed period of 1.08 days (Brettman et al. 1983). However, Griffin (1998) showed that the $1-f$ alias in the radial velocities presented by Weber & Strassmeier (1998a), i.e. a 39.5 day period, is the true orbital period of the Bab pair. In the present paper, we reanalyzed our Wolfgang *by* data but found no convincing single period despite that several equally strong frequencies for periods of 3.6, 9.5, and 16 days appear in the frequency spectrum in Fig. 1.

SAO 91772 (LN Peg). This is also BD+13°13, and is a known spectroscopic binary with an orbital period of 1.844 days (Latham et al. 1988). Henry et al. (1995b) identified it as a double-lined spectroscopic binary and determined the rotational broadening for both components (the specific values for $v \sin i$ were later revised by Fekel 1997 to 23.7 km s^{-1} and 22.5: km s^{-1} for the primary and secondary, respectively). Recently, Fekel et al. (1999) presented an orbit determination and summarized the star's fundamental properties. The light variability was discovered by Rodonó et al. (1994) who found a V amplitude of $0\overset{\text{m}}{.}08$ and a period of 1.84 days, very close to the orbital period. Further photometry was presented and analysed by Henry et al. (1995b). Their data showed several possibilities including a 1.852 day period which seems to confirm the 1.84-day period found by Rodonó et al. (1994). Our data from the 1996/97 observing season show LN Peg with a small amplitude of no more than $0\overset{\text{m}}{.}04$. The data in Fig. 2 also suggest a trend towards fainter brightness and even smaller amplitude by the beginning of the new observing season in May 1997. The periodogram shows two peaks, a stronger one at 0.5402 c/d (1.85 days), and its weaker $1-f$ alias at 0.4598 c/d (2.17 days). All data were phased with the 1.85-day period.

HD 4502 (ζ And). Its spectral classification has been repeatedly given as K1II (Bidelman 1954) but Strassmeier et al. (1989) pointed out that this is inconsistent with the radius from the rotational parameters and suggested a normal giant classification. The new Hipparcos parallax ($d = 55.6 \pm 2.4$ pc; ESA 1997) results in an absolute visual magnitude of $+0^{\mathrm{m}}.35 \pm 0^{\mathrm{m}}.06$, as expected for a K1III giant. Recently, Fekel et al. (1999) presented an orbit determination and summarized the star's fundamental properties. Previous photometry was summarized by Strassmeier et al. (1989) who found no direct signs of starspot activity from their photometry in 1983–86. The main contributor to the light curve variability is the ellipticity effect (Stebbins 1928). Kaye et al. (1995) were able to subtract that effect from the photometry and recovered the spot wave with amplitudes between $0^{\mathrm{m}}.04$ and $0^{\mathrm{m}}.003$ for data taken between 1923 and 1993. Our data from the observing season 1996/97 show a significantly different appearance than those in 1983–86 (Fig. 52 in Strassmeier et al. 1989). Most notably, the full amplitude is now $0^{\mathrm{m}}.13$ instead of $0^{\mathrm{m}}.09$, the two minima are unequal in depth, and the secondary maximum appears fainter than the primary maximum by $0^{\mathrm{m}}.05$ or 100% with respect to 1983–86. This confirms the starspot activity on ζ And.

HD 12545 (XX Tri). Besides the T Tauri star V410 Tau, HD 12545 is the most spotted star showing light amplitudes between $0^{\mathrm{m}}.4 - 0^{\mathrm{m}}.6$ in V. The average V amplitude in 1996/97 was "only" $0^{\mathrm{m}}.3$. With a maximum brightness of $\Delta V = +0^{\mathrm{m}}.375$ in February 1997 (or $V = 8^{\mathrm{m}}.170$ if we adopt the brightness for the comparison star from Strassmeier et al. 1997a), HD 12545 appeared with its brightest magnitude ever observed since the discovery of its light variability in late 1985. Figure 4 shows the data, the periodogram, and the combined phase curve.

HD 17433 (VY Ari). Strassmeier & Bopp (1992) presented a photometric study of this star with data from 1974 through 1991 and for further references we refer the reader to that paper. HD 17433 is a single-lined spectroscopic binary with an orbital period of 13.2 days and an asynchronously rotating primary with a period of 16.4 days. The largest photometric variations were seen in 1989 with an amplitude of $0^{\mathrm{m}}.28$ in V. Our new data were taken with the Phoenix-10 APT and show an unambiguous period of 16.23 days with a maximum amplitude of $0^{\mathrm{m}}.17$. Figure 5 shows a very asymmetric light curve indicative of strong starspot activity.

HD 22468 (HR 1099, V711 Tau). This star is probably the most well observed spotted stars in the sky other than the Sun and is the target of, e.g., continuing Doppler imaging by several groups (e.g. Vogt et al. 1999). It is a double-lined spectroscopic binary and consists of a K1 subgiant and a G5IV or V-IV star. Only the K1IV star is significantly active and spotted, and its light is modulated with the 2.8-day period. Our data in Fig. 6 are not corrected for the presence of the light of the G5 star and are therefore combined magnitudes. The true amplitude from the K1 star alone can be expected to be approximately 1.52-times larger than the observed combined amplitude. Also note that a third star, ADS 2644B, only $6''$ from V711 Tau, is within the $30''$ diaphragm of the Wolfgang-Amadeus APTs. Our new data were obtained with both Vienna APTs in VRI and by, the V and y data are shown separately in Fig. 6 along with the periodograms and the phase plots. The average seasonal amplitude in 1996/97 was $0^{\mathrm{m}}.15$ in V with a period of 2.837 days.

HD 26337 (EI Eri). The current data are part of a larger program to continuously Doppler image this star throughout its spot activity cycle (Washüttl et al. 1999). The combined literature and previous APT data revealed a 11-year sinusoidal light variation that may be interpreted as a spot cycle (Strassmeier et al. 1997a). Further information is given in that paper. In the present paper, we analyse new VRI data from the Amadeus APT. The average seasonal period was 1.913 days and the maximum V amplitude only $0^{\mathrm{m}}.09$.

HD 283518 (V410 Tau). This is the star with the record photometric amplitude due to spots: $0^{\mathrm{m}}.65$ in V in 1994/95 (Strassmeier et al. 1997a). During the 1996/97 observing season, its V amplitude was comparably small, the maximum peak-to-peak amplitude was $0^{\mathrm{m}}.35$ in November 1996 and approximately $0^{\mathrm{m}}.3$ for the rest of the season. The best-fit period was 1.872 days.

HR 1362 (EK Eri). In this paper, we just present the 1996/97 Amadeus data and show a plot of the V magnitudes versus time (Fig. 9). A complete analysis of much more photometry of this star, including the present data, was recently presented by Strassmeier et al. (1999b). The full amplitude in 1996/97 was $0^{\mathrm{m}}.2$ in V.

HD 283571 (RY Tau). RY Tau belongs to the class of classical T Tauri stars (CTTS) with irregular light variations. It is one of the few CTTS with sufficiently rapid rotation to make it a Doppler imaging candidate. Attention was drawn to it originally by Herbst & Stine (1984) after it had brightened by 2^{m} from 11th to 9th magnitude in 1983/84. Recently, Petrov et al. (1999) reported yet another brigthening by 1^{m} from $10^{\mathrm{m}}.6$ to $9^{\mathrm{m}}.6$ in late 1996. Neither of these papers nor Bouvier et al. (1988) found a periodic variability while Herbst et al. (1987) suggested possible periods of 5.6 and 66 days and Bouvier et al. (1993) found 24 days. Our periodogram indeed shows a peak at a frequency of 0.04 c/d (25 days) but we do not consider it significant according to our $S/N = 4$ criterion. The large $v \sin i$ of RY Tau of 50 $\mathrm{km\,s^{-1}}$ and the anticipated stellar radius of 1.8 $R_\odot$ (see Bouvier et al. 1993) suggest a rotation period of around two days. Therefore, the origin of the 24-day period – if real – still remains to be determined.

In this paper, we present our VRI light curves from 1996/97 and show that the star had faded by $1^{\mathrm{m}}.2$ in V

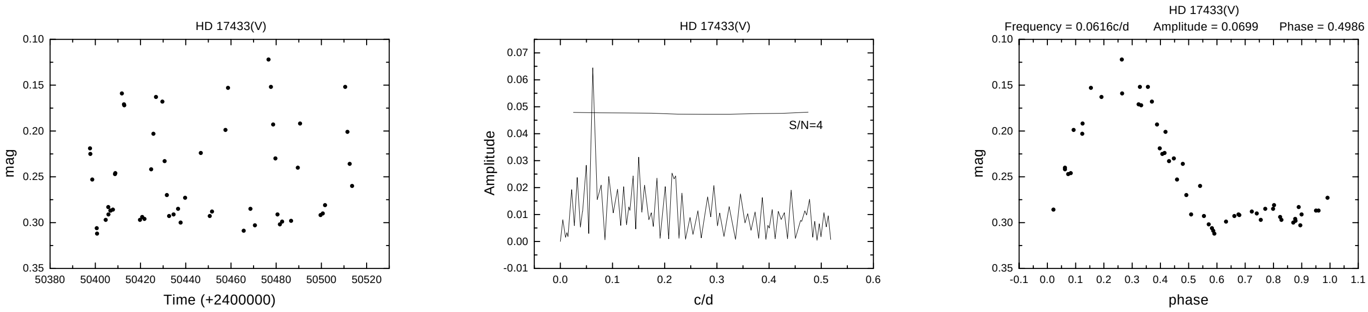

Fig. 5. As in Fig. 1 but for VY Ari. The UBV data are from the Phoenix-10 APT

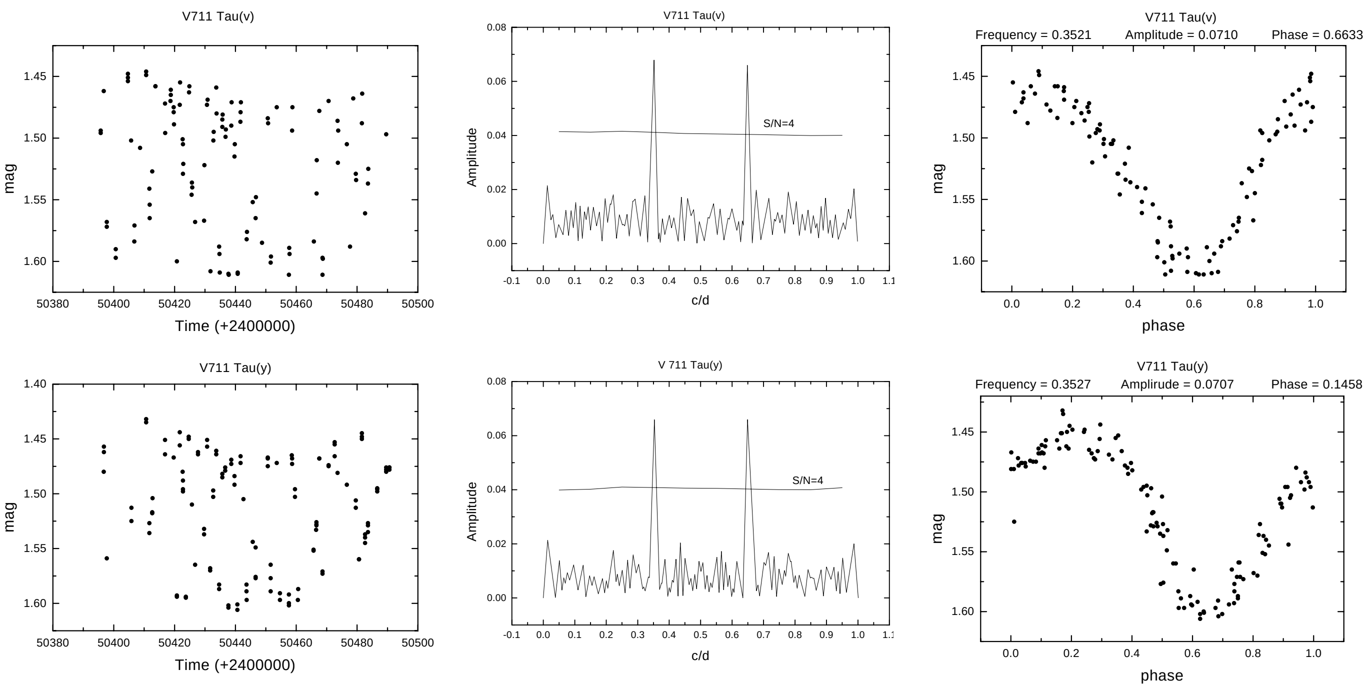

Fig. 6. As in Fig. 1 but for V711 Tau. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Wolfgang *by* data

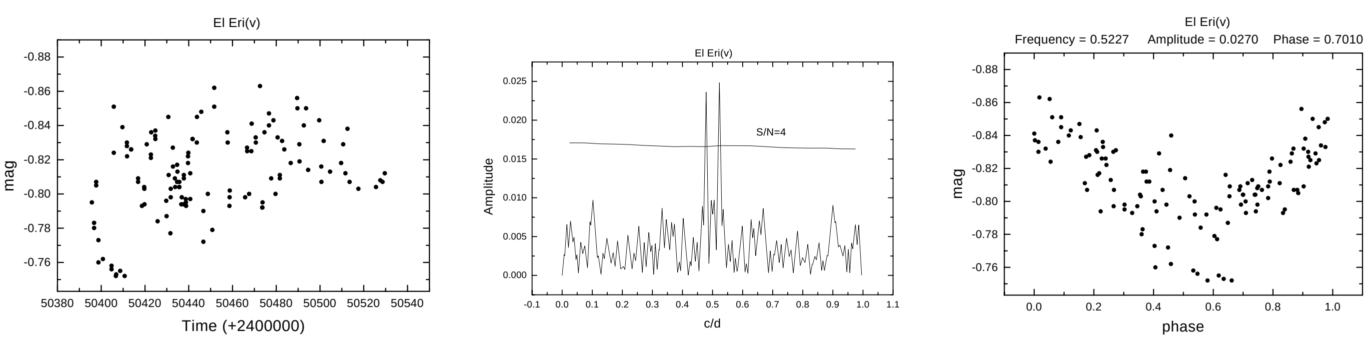

Fig. 7. As in Fig. 1 but for EI Eri

between February and March/April 1997. A preliminary report including also a $V - I$ color curve was presented as a poster paper by Granzer & Strassmeier (1998). Our period analysis from a subset of the present data (excluding the times of the brightness drop) did not reveal a clear periodicity other than the nightly aliases (Fig. 10).

HD 283572 (V987 Tau). Just recently, Strassmeier & Rice (1998b) presented a Doppler image of this pre-main-sequence star for October 1997 (i.e. in the following observing season 1997/98) that revealed a large and very cool polar spot and numerous surface detail along its rim. In this paper, we present photometry for the 1996/97 observing season (Fig. 11) and complement the data already

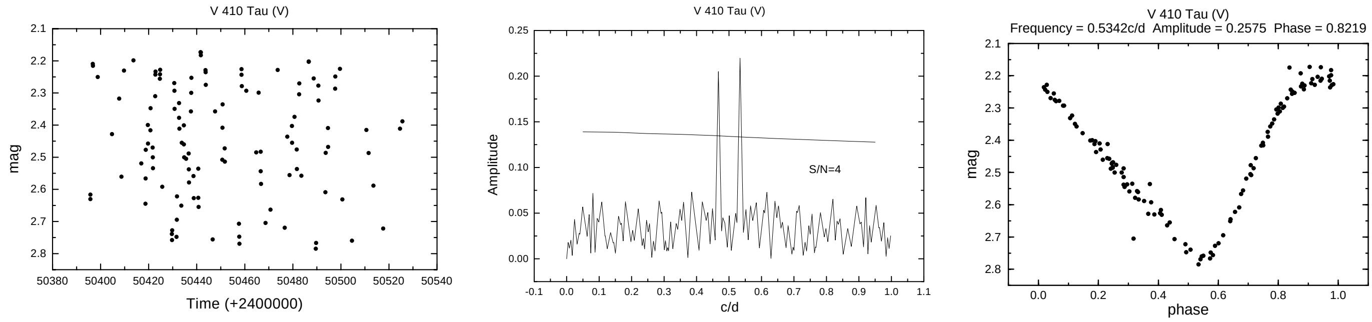

Fig. 8. As in Fig. 1 but for the WTTS V410 Tau

analysed in Strassmeier & Rice (1998b). The photometric period for 1996/97 was 1.529 days while the period from a subset of the 1997/98 data used by Strassmeier & Rice was 1.5495 days.

HD 283750 (V833 Tau). Data from three and a half observing seasons between 1992 and 1996 were presented in our previous APT paper (Strassmeier et al. 1997a) which also contained a summary of previously available photometry of this star. This season's VRI data show a rapid brightness increase by $0\stackrel{m}{.}05$ from the beginning of the observations in mid November until the end of December (Fig. 12). This change amounts to more than the amplitude due to rotational modulation of $0\stackrel{m}{.}03$, which remained almost constant throughout the season. The photometric period in 1996/97 was 1.806 days.

HD 282624 (SU Aur). SU Aur is a relatively hot, classical T Tauri star and was proposed to have an inclined magnetic dipole with respect to the stellar rotation axis (Johns & Basri 1995). A more recent study on the wind and accretion phenomena in SU Aur was presented by Unruh et al. (1998) who confirmed the phase lag between the wind signatures and the accretion signatures. It is not clear whether SU Aur exhibits periodic light variations due to rotation at all. Photometric periods between 1.55 and 3.4 days were reported by Herbst et al. (1987) and Bouvier et al. (1988) while periods from spectroscopic signatures range between 2.5 and 3.0 days (see Unruh et al. 1998). A preliminary report on our photometry, including a $V-I$ color curve, was presented as a poster by Granzer & Strassmeier (1998). Figure 13 shows the 1996/97 V data and the periodogram. No significant periods other than the nightly aliases were detected.

HD 31964 (ϵ Aur). ϵ Aur was the check star in another science group on Wolfgang and Amadeus, and here we present the Strömgren by data from Wolfgang in 1996/97. The star is the eclipsing binary with the longest known orbital period (27.1 years). The previous primary minimum occured in 1983 and the next will take place around 2009. No secondary eclipses were seen so far but might occur around 1997 ± 2 years. According to Carroll et al. (1991), the primary is a peculiar F0Ia supergiant and the secondary a close binary of two BV stars that are surrounded by a tilted disk with a central whole. Our by data in Fig. 14 show irregular, short-term, light variations with an amplitude of $\approx 0\stackrel{m}{.}01$ in y but otherwise no evidence for a classical occultation or transit.

HD 31993 (V1192 Ori). For relevant references, we refer to our previous APT paper (Strassmeier et al. 1997a). The data from the observing season 1996/97 verify the ≈28-day period found in that paper. The amplitude was still rather small, between $0\stackrel{m}{.}01$ during December 1996 and $0\stackrel{m}{.}02$ thereafter. The V-light curve in Fig. 15 suggests a downward trend of the mean brightness, opposite to what was seen during the previous observing season.

HD 33798 (V390 Aur). Fekel & Marschall (1991) presented a detailed study of this lithium rich and rapidly-rotating late-type star. As such its evolutionary state is highly unusual because all spectral information indicates that it is a single, evolved star of spectral classification G8III, and thus should have slowed down its rotation and depleted its surface lithium for a long time. Spurr & Hoff (1987) found the star to be variable with a 9.8-day period and an amplitude of $0\stackrel{m}{.}05$ in V, that was confirmed by Hooten & Hall (1990) from additional data and interpreted as the rotation period of the star. Our new data were gathered with Amadeus in VRI and show an increasing overall brightness level within the 50-night observing interval from February to April 1997 (Fig. 16). The periodogram gives only a very weakly defined frequency at 0.1032 c/d (9.69 days) but is consistent with the period found by Spurr & Hoff (1987). The maximum peak-to-peak amplitude in V was $0\stackrel{m}{.}03$ in late March.

HD 291095 (V1355 Ori). HD 291095 was detected in the ROSAT WFC all-sky survey and Cutispoto et al. (1995) discovered its light variability with a period of 3.82 days. At the time of their observations in late 1993, it showed one of the largest amplitudes of a spotted star ($0\stackrel{m}{.}37$ in V). Its colors and optical spectrum are consistent with a binary K1-2IV + G2V system (Cutispoto et al. 1995; Osten & Saar 1998) but a single K1-2IV classification can not be fully ruled out. Our 1996/97 data show the light curve with an amplitude of up to $0\stackrel{m}{.}25$ in V and a period of 3.87 days (Fig. 17).

HD 43989 (V1358 Ori). Cutispoto (1995) discovered the light variability of HD 43989 with a period of 3.63 days after it was detected in the ROSAT WFC

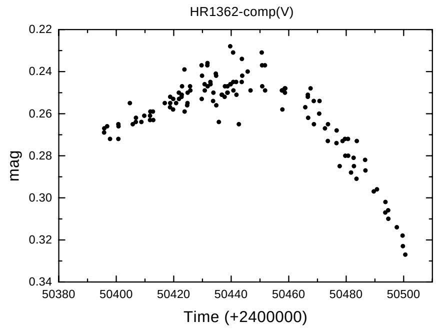

Fig. 9. V-band light curve for HR 1362 in 1996/97

all-sky survey. The star was also included in a recent study on stellar physical properties by Osten & Saar (1998). From synthesis of the optical spectrum it was not possible to distinguish between a double subgiant (composite) spectrum with equal rotational broadening of 25 km s^{-1} or a single subgiant with twice the rotational broadening ($v \sin i \approx 42$ km s^{-1}). During the 1996/97 observing season, the star was observed with both Vienna APTs in VRI and by. The number of individual data points was rather sparse and the separated light curves and periodograms did not show any obvious signs of periodic variability. Therefore, we decided to combine them by applying the transformation $y \rightarrow V$ from Olsen (1983). Figure 18 shows the combined y and V data. The total range of magnitudes was $0\overset{\mathrm{m}}{.}05$, usually already a moderately large amplitude, but no significant period was detected. The largest peak in the periodogram in Fig. 18 is at 0.305 c/d (3.28 days) and well below the $S/N = 4.0$ criterium. Nevertheless, we adopt this frequency to phase the data but emphasize that it is accordingly uncertain and possibly even spurious.

HD 51066 (CM Cam). A subset of the Amadeus data was recently used for the Doppler imaging efforts of Strassmeier et al. (1998a). HD 51066 is an interesting target because it is a single *and* rapidly-rotating giant. Attention was first drawn to it by W. Bidelman (private communication), and Henry et al. (1995b) presented photometric data from a full season in 1994 that showed the star with a period of 16.2 days and an amplitude of $0\overset{\mathrm{m}}{.}05$ in V. In 1996/97, HD 51066 showed an amplitude of between $0\overset{\mathrm{m}}{.}01$ and $0\overset{\mathrm{m}}{.}02$ in V throughout the entire observing season (Fig. 19) suggesting that its spot distribution was either relatively symmetric or its activity level very low. Our period analysis shows a 16.0-day period and thus confirms the 16.2-day period found earlier by Henry et al. (1995b).

HD 62044 (σ Gem). Henry et al. (1995a) summarized and analyzed all available photometry up to May 1992 and we refer the reader to this paper. Our new data is from the Wolfgang APT and was taken in Strömgren b and y. A maximum amplitude of $0\overset{\mathrm{m}}{.}12$ in y was seen in November-December 1996 that faded to approximately $0\overset{\mathrm{m}}{.}08$ by February 1997. Figure 20 shows the seasonal light curve, the periodogram, and the phased y light curve with a period of 19.615 days.

HD 81410 (IL Hya). Weber & Strassmeier (1998b) presented an extensive study of this star including our 1996/97 season's photometry and determined a first SB2 orbit. Recently, Fekel et al. (1999) presented an updated SB2 orbit and summarized the star's fundamental properties. In the present paper, we perform an independent period analysis for all three bandpasses and confirm the long-term average period used in our previous APT paper. Figure 21 shows the data, the periodogram, and the phased light curve with $P = 12.674$ days. Just recently, Cutispoto (1998) published further $UBVRI$ data from 1992.

HD 82443 (DX Leo). Henry et al. (1995b) found a photometric period of 5.43 days. A thorough discussion of the available literature is included in that paper. Strassmeier et al. (1997a) presented new APT data from 1994 and 1995 and found a long-term declining brightness by $0\overset{\mathrm{m}}{.}1$ between 1989 and 1996. Possibly, this is part of a cyclic behavior and further monitoring of HD 82443 is desired. In this paper, we present new UBV photometry from the Phoenix-10 APT that first show a decline of the amplitude until HJD 2 450 470 and then a rapid increase until the end of the observations (Fig. 22). The maximum amplitude of $0\overset{\mathrm{m}}{.}10$ in V was reached around 2 450 570. As a comparison the minimum amplitude near 2 450 470 was $0\overset{\mathrm{m}}{.}035$. The periodogram shows the strongest frequency at 0.1841 c/d (5.432 days), in excellent agreement with the period discovered by Henry et al. (1995b).

HD 82558 (LQ Hya). LQ Hya is a single, young and rapidly-rotating K2V star that attracted many studies in the past years. A recent Doppler image was presented by Rice & Strassmeier (1998) from CFHT observations in early 1995. Cutispoto (1998) published new $UBVRI$ data from February 1992, and the star was also a target in our previous APT paper (Strassmeier et al. 1997a). The long-term light curves in that paper revealed a sinusoidal modulation with a period of around 7 years. In the present paper, we add another full season of UBV and VRI photometry from the Amadeus and the Phoenix-10 APTs. The maximum V amplitude in 1996/97 was $0\overset{\mathrm{m}}{.}06$, thus twice as large as in the previous season but twice as small as in 1994/95. The best-fit period was for both data sets 1.60 days. The considerable scatter in the phase plot in Fig. 23 indicates a rapidly changing spot distribution.

HD 98230 (ξ UMa B). HD 98230 is the B component of the visual binary ξ UMa (AB) and is only $2''$ away from A. Both visual components are also (single-lined) spectroscopic binaries but it is the primary of the B component (a G5V star) that shows strong Ca II H&K emission which is a measure of magnetic surface activity. The orbital periods for the A and B components are 669 and 3.98 days, respectively. For relevant literature data and references, we refer to the CABS catalog (Strassmeier et al. 1993). Our differential photometry through a $30''$ diaphragm includes both

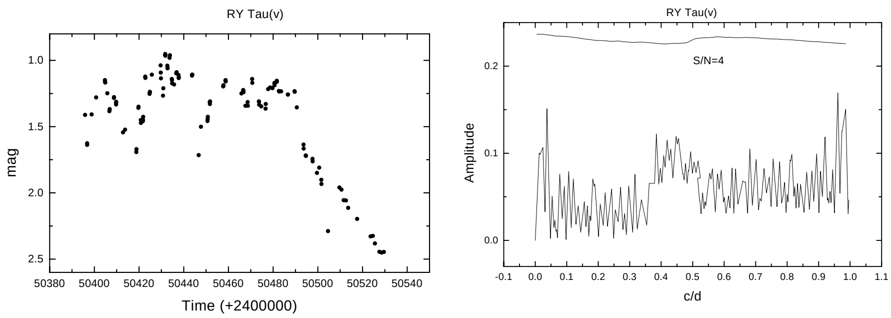

Fig. 10. As in Fig. 1 but for RY Tau. No significant period was found but the strongest peak at 25 days ($f = 0.04$) is in agreement with the period found earlier by Bouvier et al. (1993)

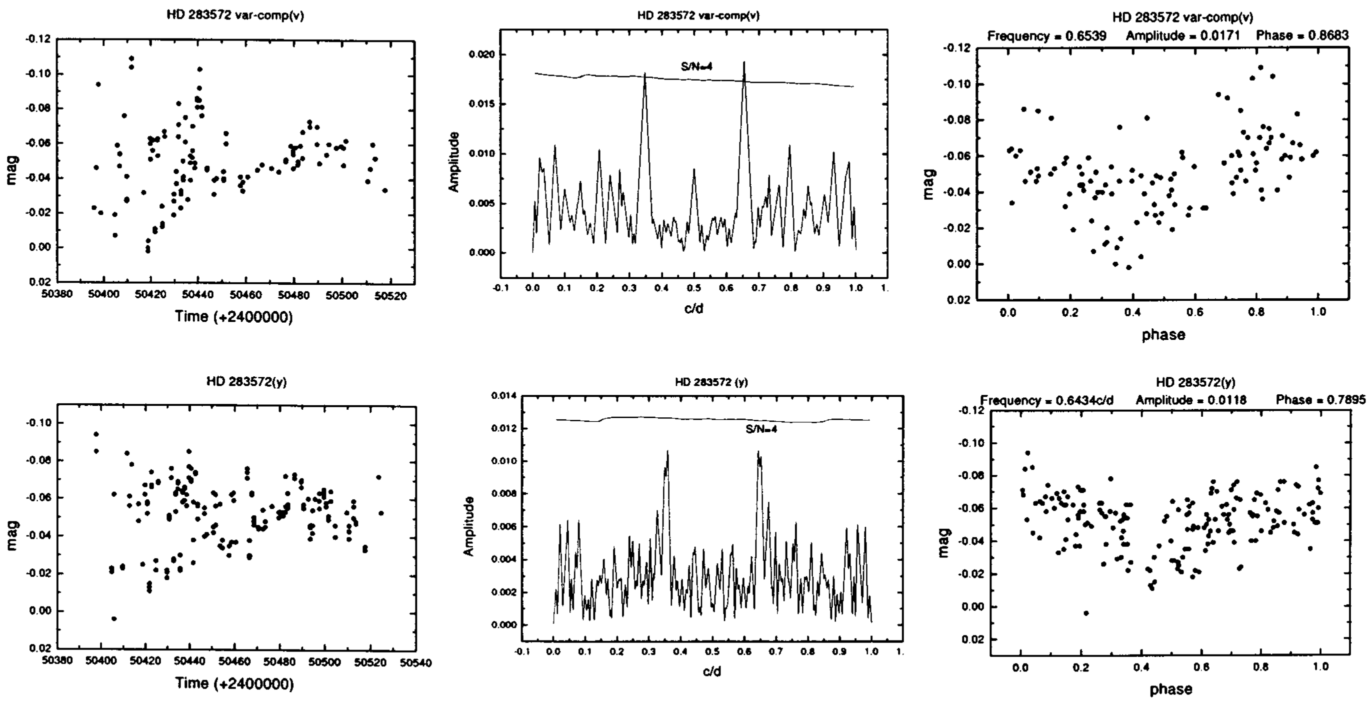

Fig. 11. As in Fig. 1 but for HDE 283572. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Wolfgang *by* data

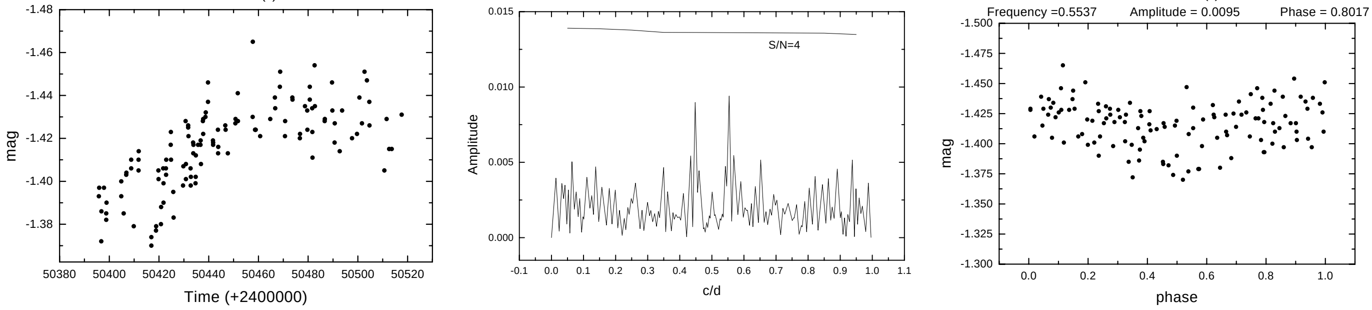

Fig. 12. As in Fig. 1 but for V833 Tau

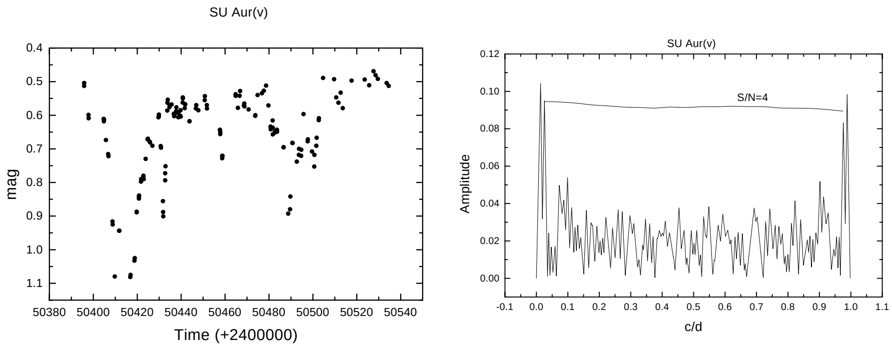

Fig. 13. Light curve and periodogram for SU Aur. No significant periodicity was found. See text

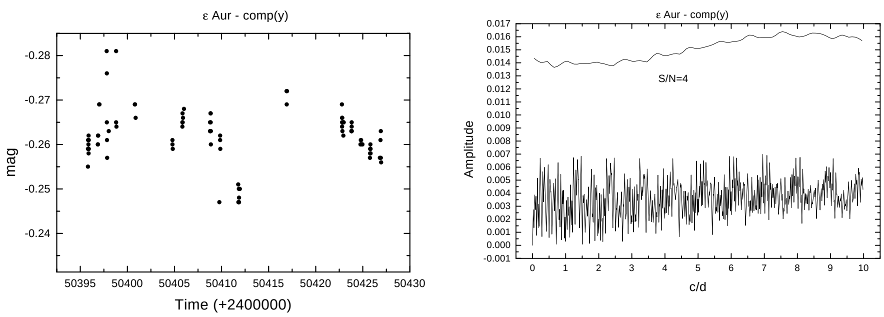

Fig. 14. Light curve and periodogram for ϵ Aur. No significant periodicity was found. See text

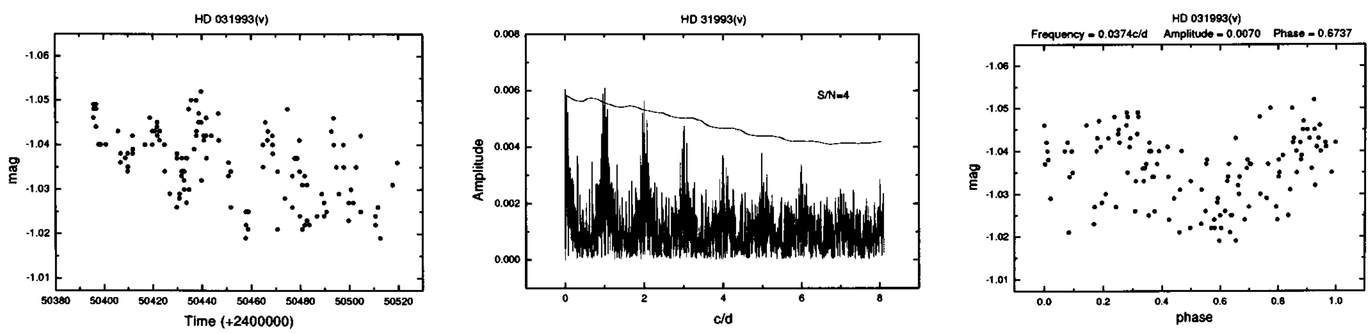

Fig. 15. As in Fig. 1 but for HD 31993

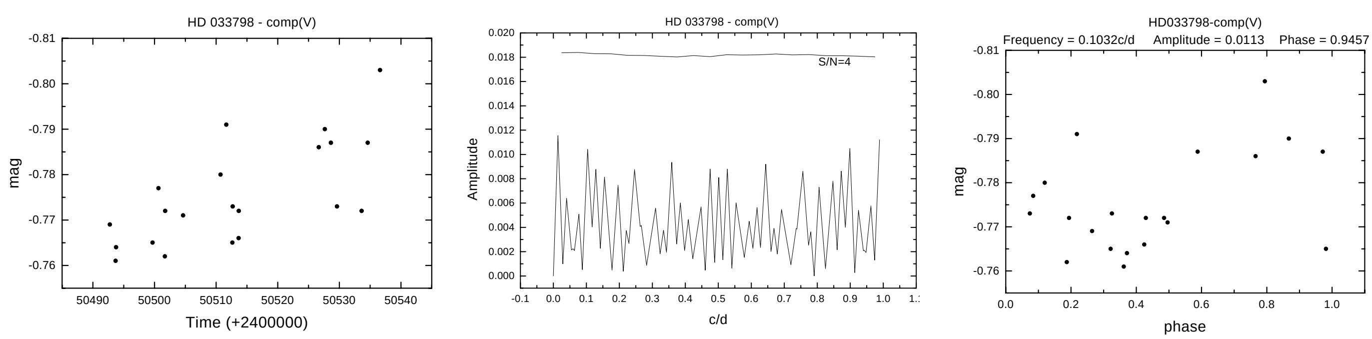

Fig. 16. As in Fig. 1 but for HD 33798

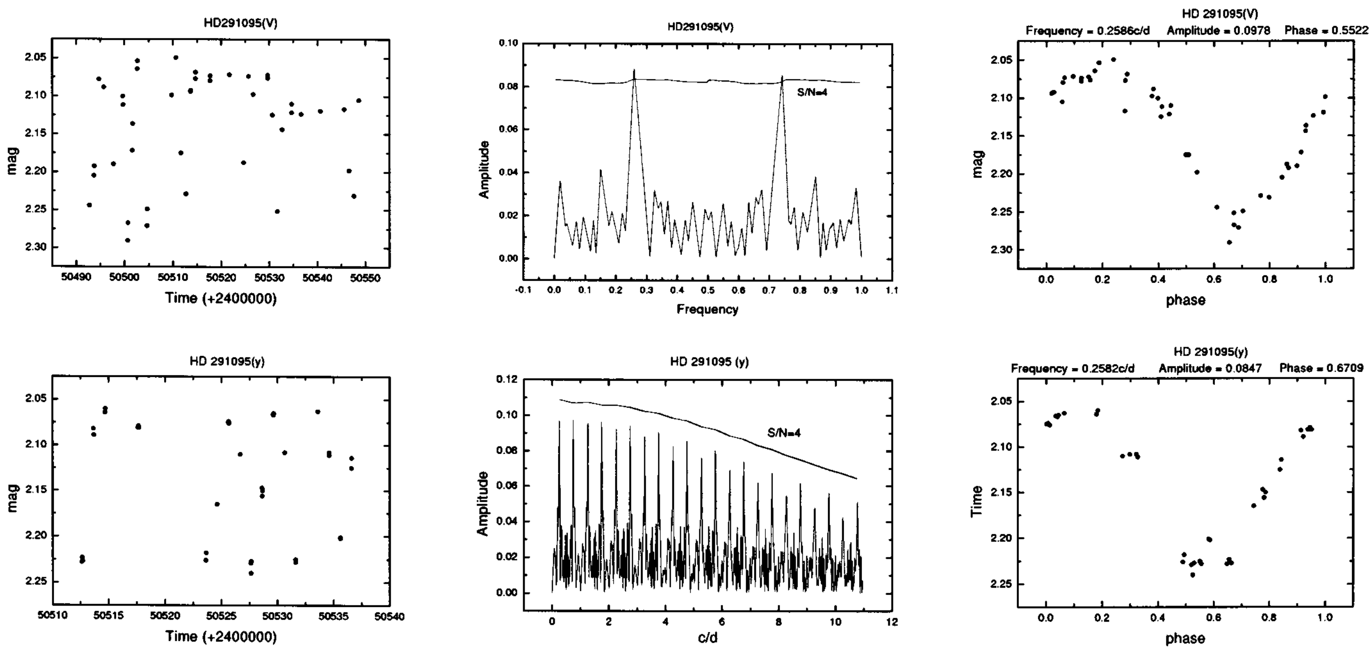

Fig. 17. As in Fig. 1 but for HDE 291095. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Wolfgang *by* data

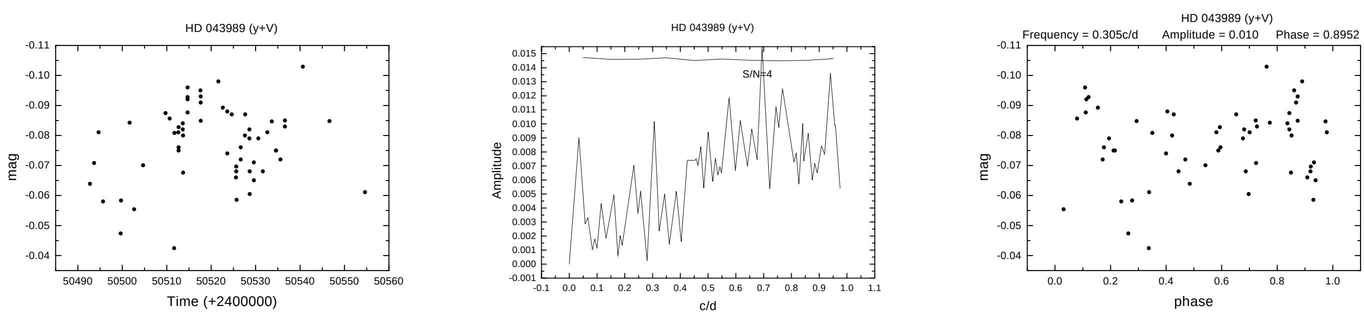

Fig. 18. As in Fig. 1 but for HD 43989. The panels show the combined Wolfgang y data and Amadeus V data

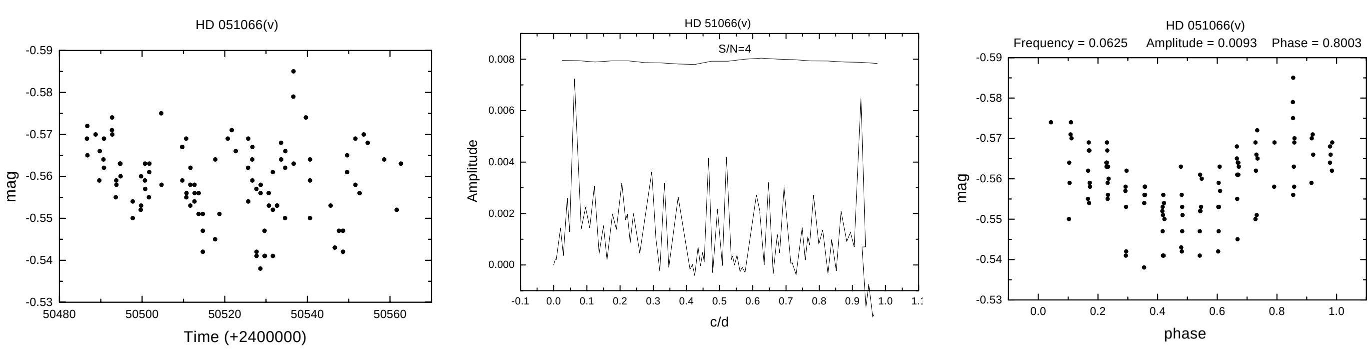

Fig. 19. As in Fig. 1 but for HD 51066

spectroscopic binaries. Strassmeier et al. (1989) presented BV photometry from 1984 to 1986 that indicated a long-term variability of $0\overset{m}{.}05$ in V and a possible periodicity of around 800 days. No short periods close to the orbital period of the B components were found. From the present data, we confirm the absence of a short period that could stem from rotational modulation (Fig. 24). A long-term trend is nevertheless obvious from Fig. 24; its observed amplitude amounts to $\approx 0\overset{m}{.}015$ in y and agrees with the possible period of 800 days suggested by Strassmeier et al. (1989).

HD 106225 (HU Vir). Cutispoto (1998) published further $UBVRI$ data from 1992 that was not included in Strassmeier et al. (1997a). Hatzes (1998) updated and summarized the previous Doppler imaging efforts and Fekel et al. (1999) presented a new orbit determination

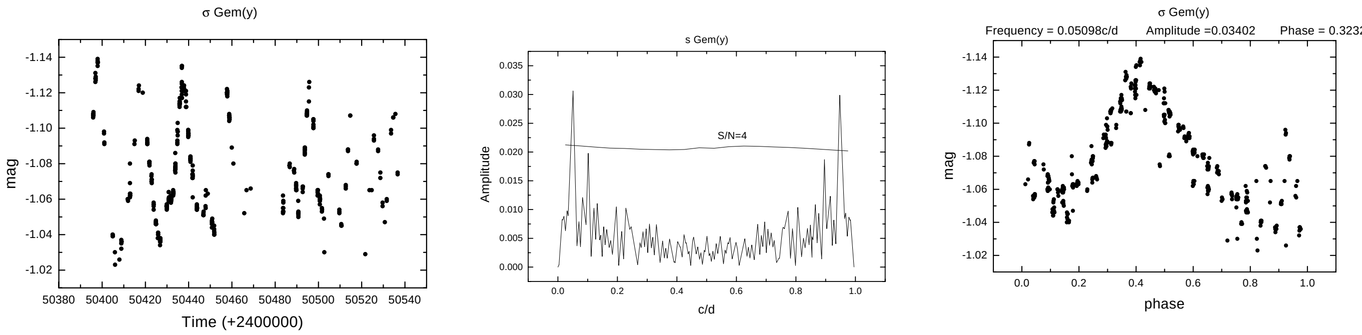

Fig. 20. As in Fig. 1 but for σ Gem

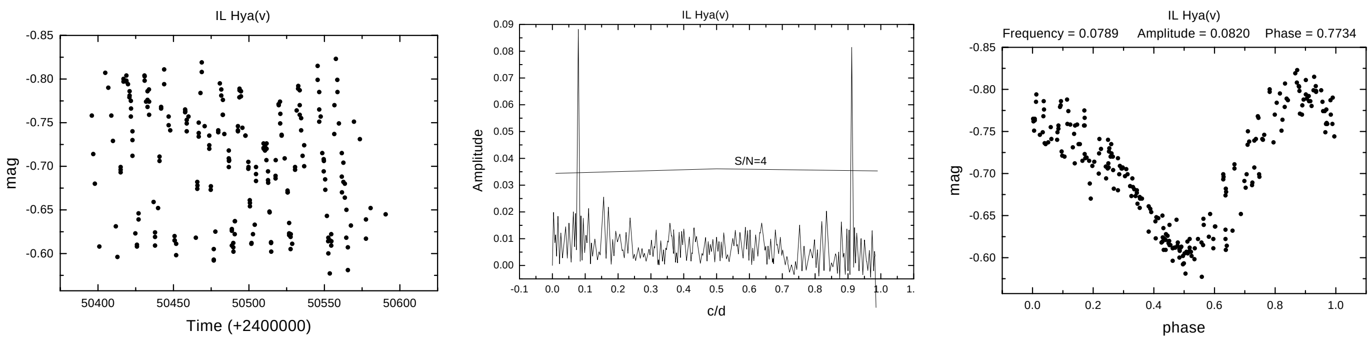

Fig. 21. As in Fig. 1 but for IL Hya

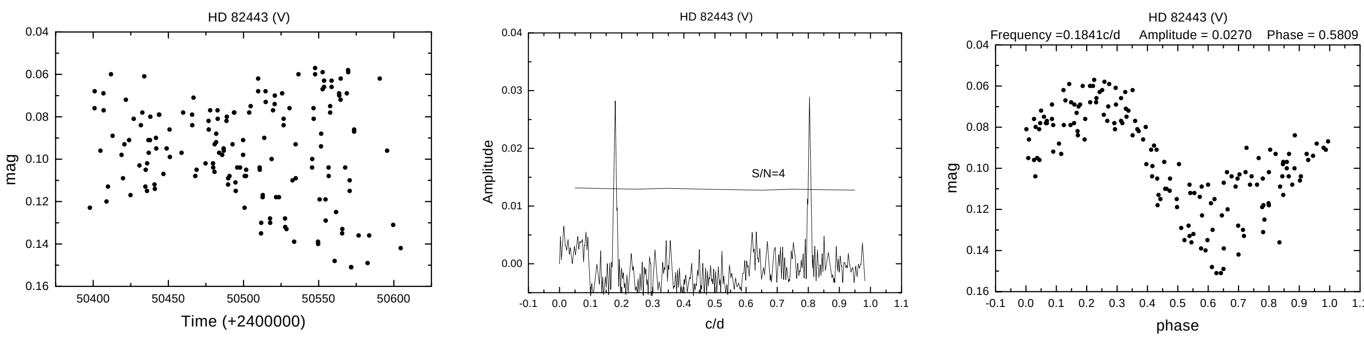

Fig. 22. As in Fig. 1 but for HD 82443 All UBV data are from the Phoenix-10 APT

and summarized the star's fundamental properties. For more information on this very active RS CVn star, we refer to any of these papers. Our new 1996/97 VRI data show the star with a variable light-curve amplitude ranging from $0\overset{m}{.}2$ in December 1996 to $0\overset{m}{.}1$ in March/April 1997 and back to $0\overset{m}{.}25$ in June 1997 (see Fig. 25). The period from the more numerous Amadeus data was 10.66 ± 0.01 days and is confirmed by the Phoenix-10 data which yielded a more uncertain 10.60-day period. The "scatter" in the phased light curves in Fig. 25 indicates the large degree of spot activity of this star.

HD 111395 (HR 4864). Strassmeier et al. (1997c) presented some early photometric and spectroscopic data and concluded that the star is a spotted and chromospherically active, single, solar-type star of spectral type G5. They found a period of 16.95 days and sinusoidal light variations with an amplitude of around $0\overset{m}{.}02$ in V. Part of their photometry is included in the data set in this paper and is from the Amadeus APT. Here, we basically confirm their results but refine the period to 15.80 days. Figure 26 shows a monotonic increase of the light curve amplitude from $0\overset{m}{.}02$ at the beginning of the observing season up to $0\overset{m}{.}06$ at the end. The phase curve in the right panel in Fig. 26 appears accordingly scattery.

HD 111812 (31 Com). This star is a rapidly rotating G0 giant that exhibits strong chromospheric activity. Consequently, cool starspots could be expected but, so far, no photometric variability due to rotational modulation was detected. Previous APT data was analyzed in Strassmeier et al. (1997a), and for more references we refer the reader to the discussion in that paper. No clear periodicity was seen but the star seemed to show seasonal brightness changes that were also noted in earlier

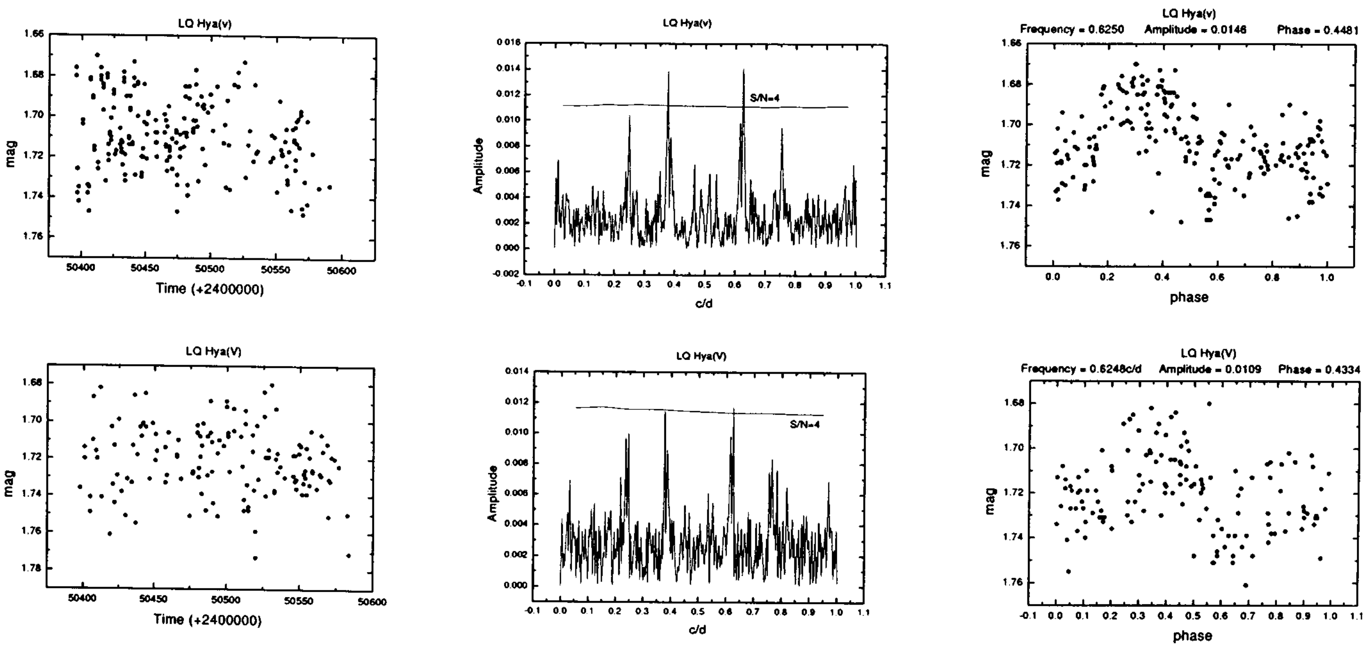

Fig. 23. As in Fig. 1 but for LQ Hya. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Phoenix-10 UBV data

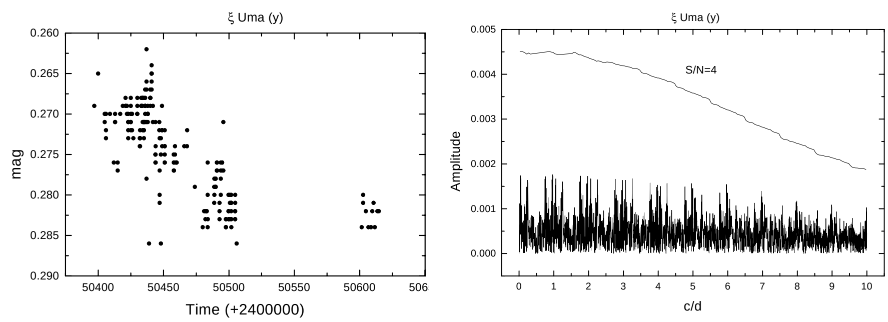

Fig. 24. As in Fig. 1 but for ξ UMa. Note that all detected frequencies in the periodogram in the right panel are aliases of the one-day observing interval

observations by Lockwood et al. (1997). In this paper, we present further UBV data from the Phoenix-10 APT. Figure 27 shows the U and V light curves for 1996/97 (upper and lower left panels, respectively), the periodogram analysis for the U-band data (middle panels), and two phase curves with two possible periods (right panels). We verify the existence of seasonal brightness changes of approximately $0\overset{\mathrm{m}}{.}01$ in V. The period analysis of these data and their residuals revealed two possible periods besides the one-day alias (the alias is marked f_1 in Fig. 27): a 0.1437-c/d peak according to a period of 6.96 days (marked as f_2), and a 0.4331-c/d peak, i.e. 2.31 days, marked as f_3 (another frequency marked as f_4 is already considered to be too weak). Note that the phase curve with the 6.96-day period includes the systematic scatter due to the one-day aliasing and shows a full amplitude of no more than $0\overset{\mathrm{m}}{.}01$ in U. The Fourier amplitude of the 6.96-day period is twice as large as the 2.31-day period and we may consider it as the (preliminary) discovery of the rotation period of 31 Comae but emphasize that it is accordingly uncertain and possibly even spurious.

HD 112313 (IN Com). Photometry from various sources between 1983 and 1996 was collected and analysed by Strassmeier et al. (1997a), while Strassmeier et al. (1997d) obtained a Doppler image and a full season of additional photometry of this outstanding star. The star is the G5III-IV component of a triple system that includes one of the hottest known stars. The latter is the central star of the planetary nebulae LoTr-5. The rotation period of the G5 giant was unambiguously determined as 5.913 days (instead of 1.2 days) and made IN Comae a very rapidly rotating late-type star with an equatorial velocity of 95 km s^{-1}. As such, it very much resembles the class of (single) FK Comae-type stars. Our data for 1996/97 were gathered contemporaneously with both Vienna APTs to increase the time resolution and overcome the false period alarm. Both data sets showed the star with an amplitude of $0\overset{\mathrm{m}}{.}06$ in V and a period of 5.900 and 5.927 days for the Amadeus and Wolfgang

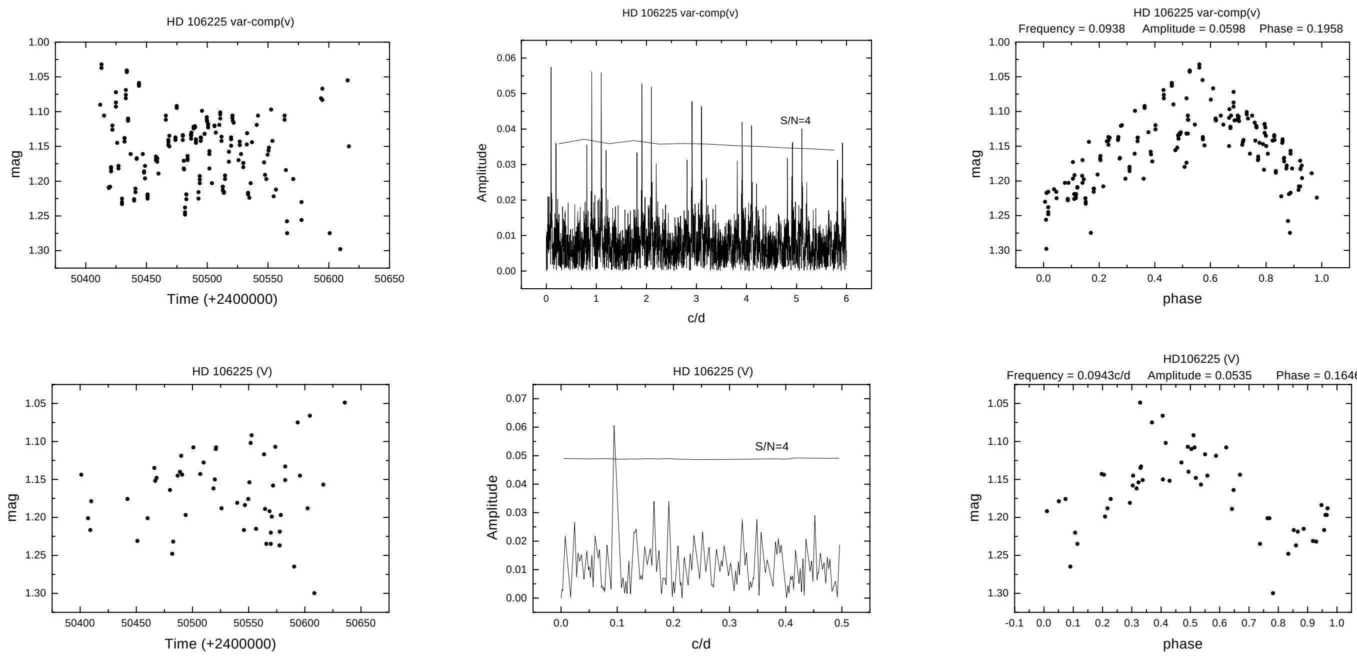

Fig. 25. As in Fig. 1 but for HD 106225. *Top row:* Amadeus $V(RI)_{\rm C}$ data. *Bottom row:* Phoenix-10 UBV data

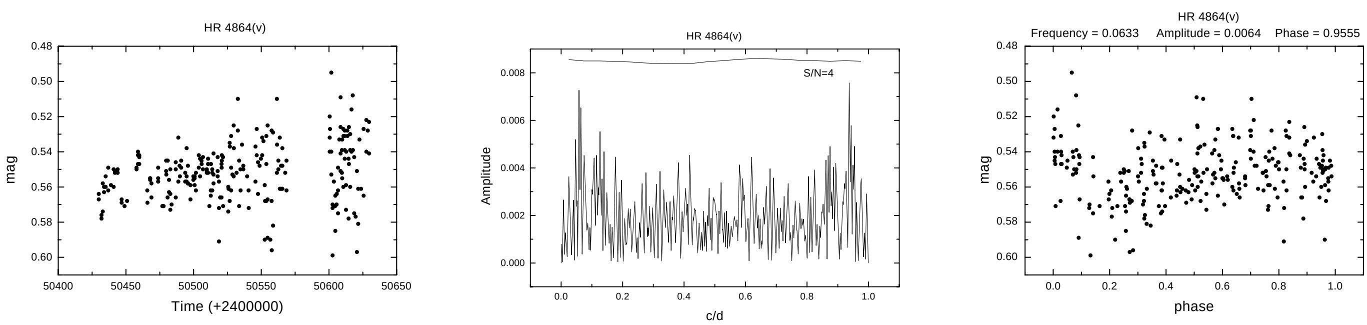

Fig. 26. As in Fig. 1 but for HR 4864

data, respectively. Figure 28 shows the V and y light curves and the respective periodograms.

HD 112989 (37 Com). Strassmeier et al. (1997b) used 37 Com as the check star in their 1996 campaign on 31 Comae and found the star to be a long-term variable possibly with a period of around 80 days. 37 Comae was classified as a single G9IIICH-2 giant by Keenan & McNeil (1989). We obtained a single, high-resolution spectrum centered at 3950 Å at KPNO that shows weak Ca II H & K emission with asymmetric absorption reversals due to interstellar absorption, that indicates a giant luminosity class. $V \sin i$ from a red wavelength spectrum, obtained also at KPNO, is estimated to be 4 ± 2 km s^{-1} (adopting a macroturbulence of 3 km s^{-1}). With a nominal radius of 10 $R_\odot$ for a G9III star, we could expect a rotation period in the range of approximately 70–170 days for $i \approx 45°$. Our data over a 150-day interval in Fig. 29 show no significant period above the $S/N = 4$ criterion. A weak peak at 0.12 c/d (8.3 days) and its $1-f$ alias (1.1 days) is judged spurious. Despite of the increase of "scattered" data toward the end of the observing season, we conclude that the star was constant in 1996/97.

HD 117555 (FK Com). Too numerous is the literature on FK Comae to be cited here and we refer the reader to the discussion of FK Comae in our previous APT paper (Strassmeier et al. 1997a). Since then, Strassmeier et al. (1997b) presented four months of continuous and phase-resolved *by* data with the Wolfgang APT from early 1996 that were aimed to demonstrate the telescope's capabilities. In the present paper, we present the 1996/97 *by* data from Wolfgang. The y light curve in Fig. 30 shows a full $0^{\rm m}\!.2$ amplitude in late 1996 and early 1997 that smoothly decreased to $0^{\rm m}\!.13$ within 10 stellar rotations and then remained constant through the end of the observing season in late June 1997. The average photometric period was 2.4067 days, only 0.001% different from the period from early 1996.

HD 129333 (EK Dra). The present $BV(RI)_{\rm C}$ data on EK Dra were partially analysed in Strassmeier & Rice (1998a) where they were used as additional constraint for

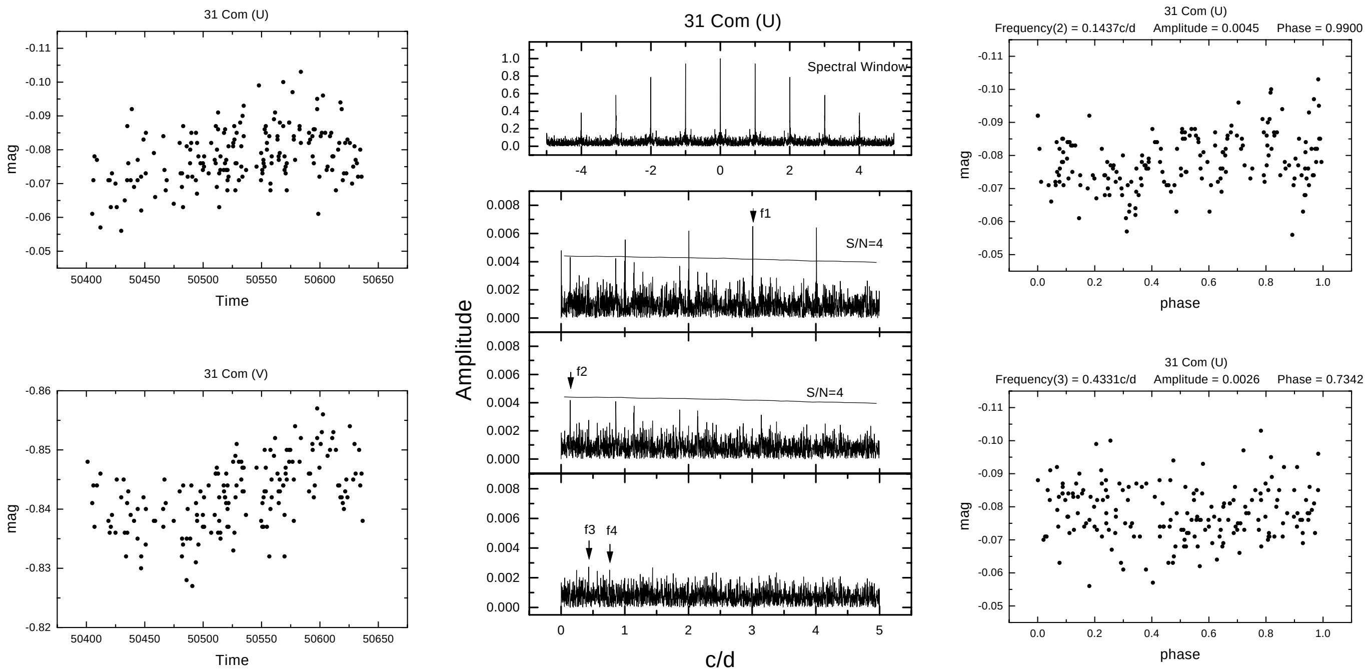

Fig. 27. U and V light curves for 31 Com (left two panels). The two middle panels show the spectral window (top panel) and the periodograms from the U-band data (three lower panels). The first plot is the original periodogram showing the one-day aliases (indicated by f_1), the second plot is the periodogram with f_1 subtracted. It shows the most likely period from our data set and is marked with f_2 (0.1437 c/d = 6.96 days). The third plot is the periodogram with f_2 subtracted. It identifies two frequencies (f_3 and f_4) that are both considered too weak though. The right panels are the phased U-light curves with the two frequencies f_2 and, as a comparison, f_3 (0.4331 c/d = 2.31 days), respectively. All data are from the Phoenix-10 APT

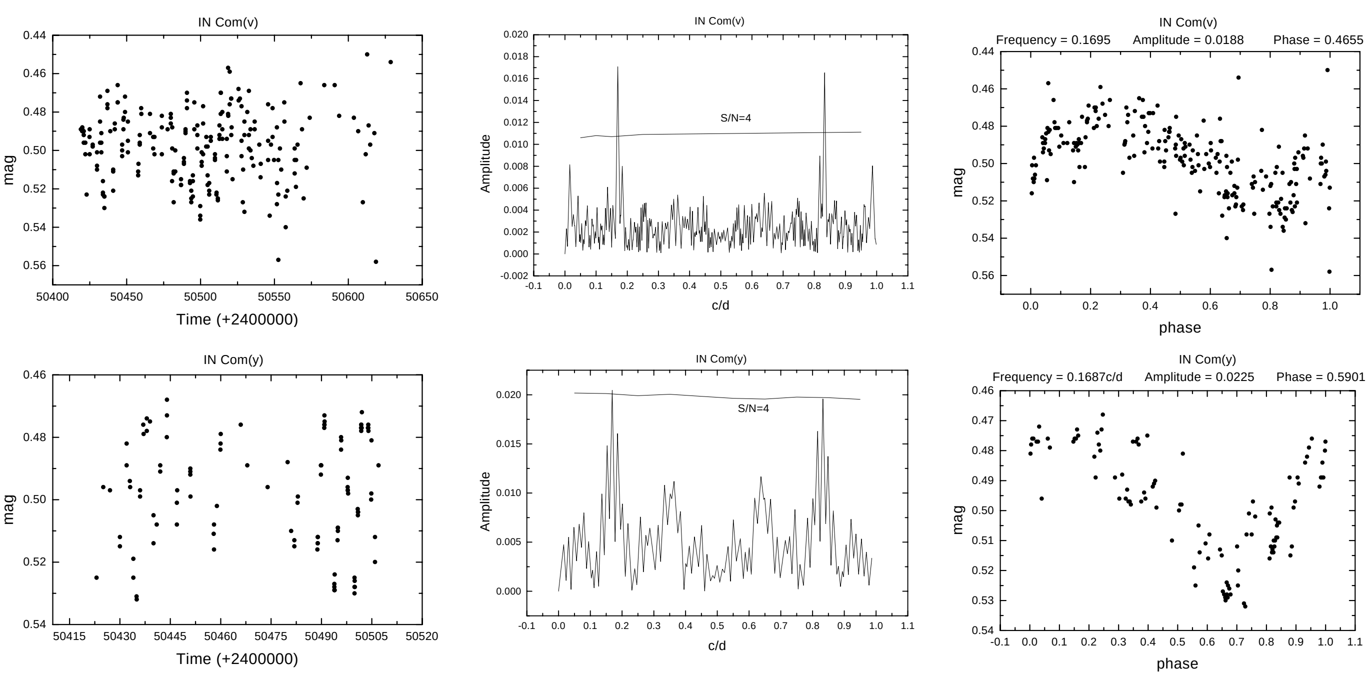

Fig. 28. As in Fig. 1 but for IN Com. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Wolfgang *by* data

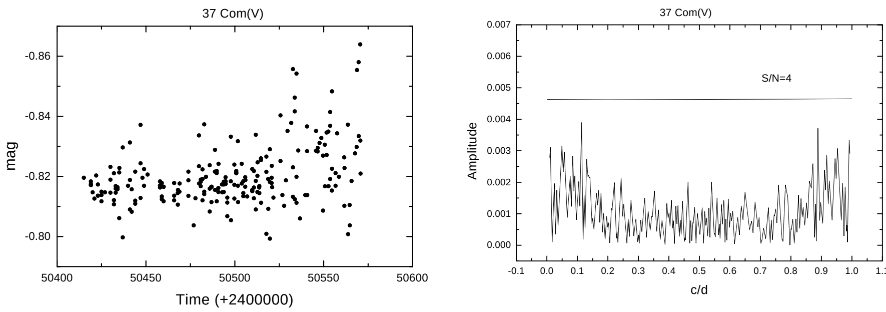

Fig. 29. Seasonal V data and the periodogram for 37 Com. No single significant period was found

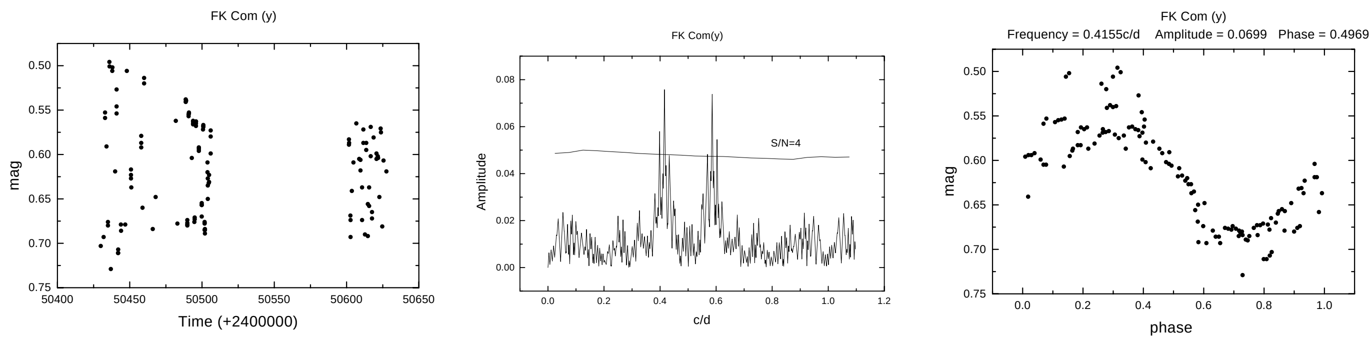

Fig. 30. As in Fig. 1 but for FK Com. All data are from the Wolfgang APT and were taken in b and y

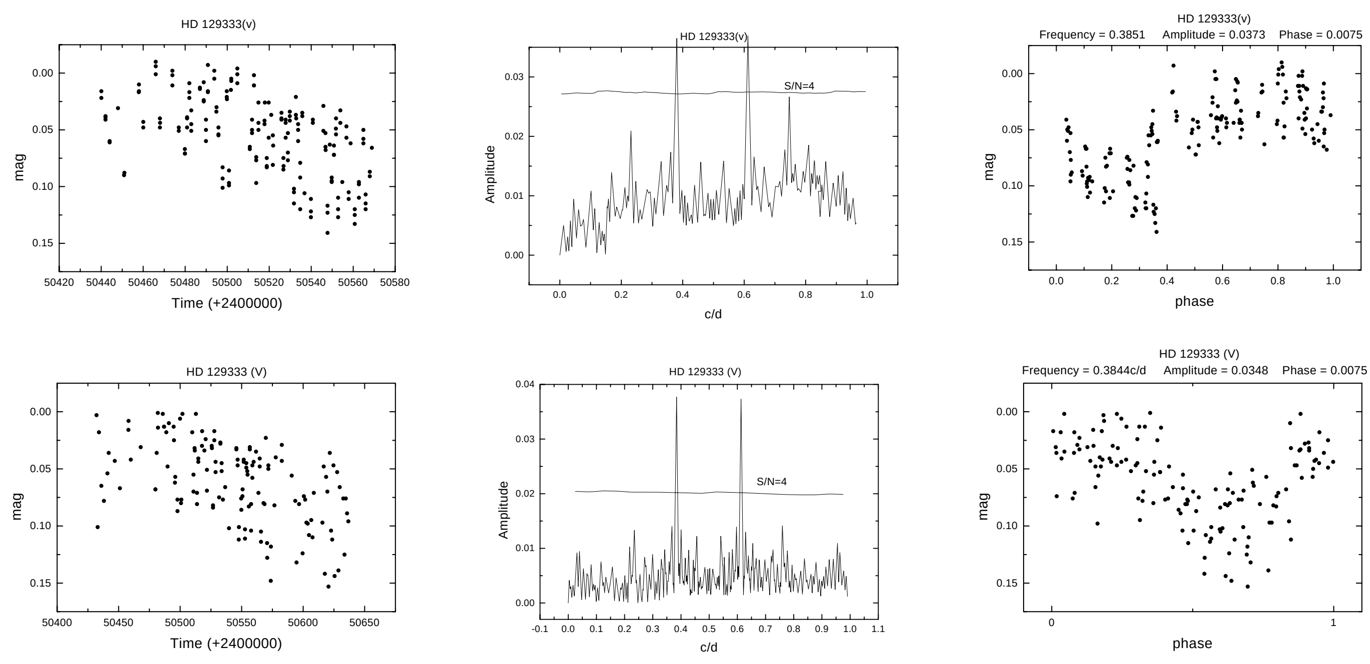

Fig. 31. As in Fig. 1 but for HD 129333. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Phoenix-10 UBV data

Doppler imaging. Here, we simply present the numerical data from the Amadeus and Phoenix APTs from 1996/97 and perform a period analysis of the separate data sets. The best periods were 2.597 days and 2.601 days for the Amadeus and Phoenix-10 data, respectively. Thus, we confirm our earlier photometric period of 2.599 days from the combined V data. For reasons of completeness, we plot the data in Fig. 31 along with a periodogram from the V data.

HD 136901 (UV CrB). This star is a massive ellipsoidal K1 giant in a single-lined spectroscopic binary (Fekel et al. 1989). Its light variations are attributed mainly to the ellipticity effect with some contribution from the reflection effect (Strassmeier et al. 1989). Recently, Fekel et al. (1999) presented a new orbit and summarized the star's

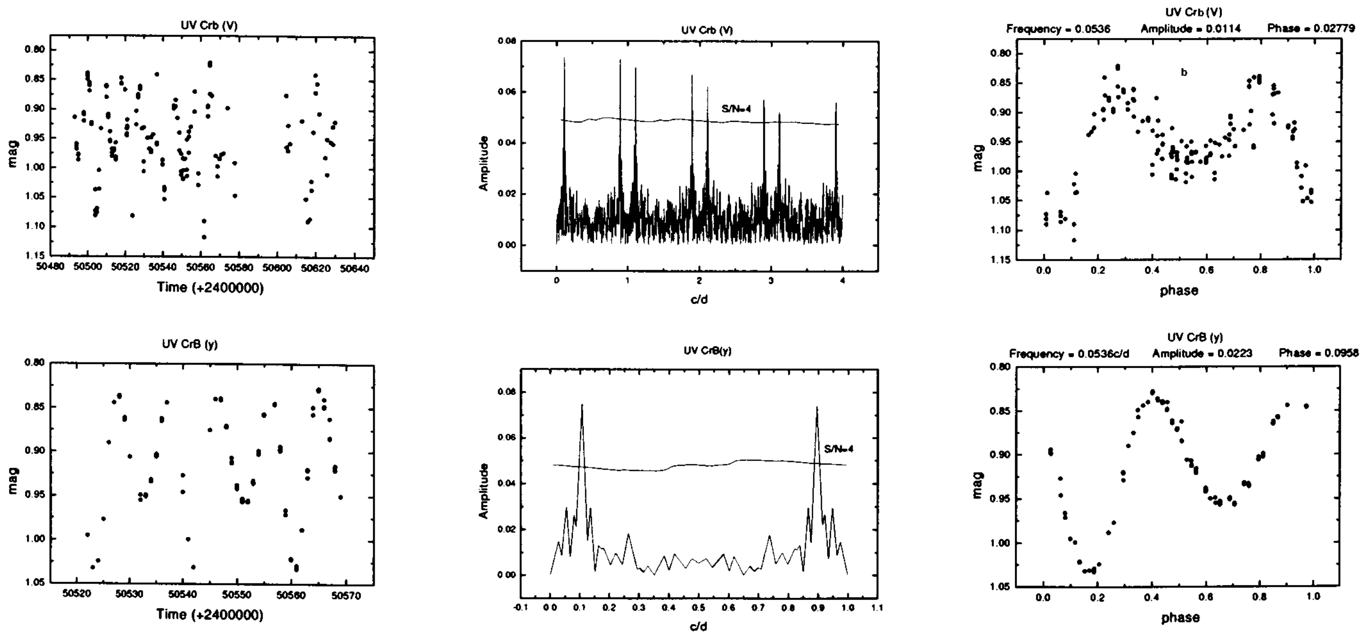

Fig. 32. As in Fig. 1 but for UV CrB. *Top row:* Amadeus $V(RI)_C$ data. *Bottom row:* Wolfgang *by* data

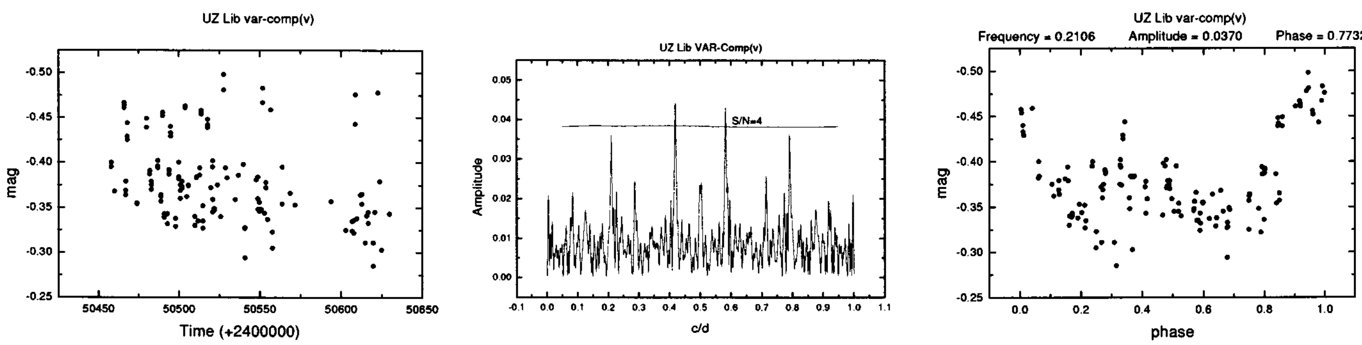

Fig. 33. As in Fig. 1 but for UZ Lib

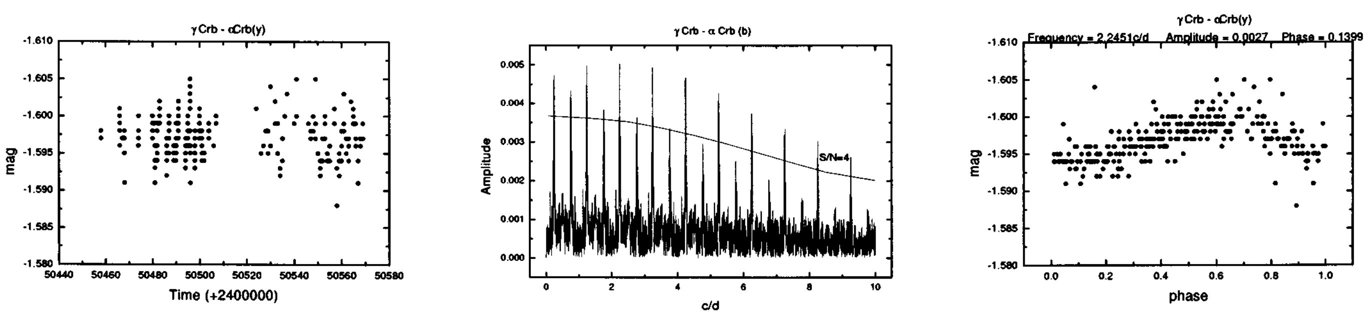

Fig. 34. Strömgren b light curve for γ CrB minus α CrB

fundamental properties. Kaye et al. (1995) suceeded in extracting the spot component out of the combined light curves and found amplitudes between $0\overset{m}{.}048$ and $0\overset{m}{.}009$ in V. For 1996/97, we had UV CrB on both Vienna APTs in order to search for further evidence of starspot activity. Figure 32 shows the data from both telescopes along with the periodograms and phased light curves. The best-fit frequency was 0.107 c/d (9.33 days) but, because the ellipticity effect causes a double-humped light curve, the true period is at $f/2$. Thus, the light curve in Fig. 32 was phased with a period of 18.657 days. The scatter in the seasonal phase plot from the Amadeus telescope is mostly due to intrinsic changes during the observing season. Note that the time coverage of the Wolfgang data is only one half that of the Amadeus data.

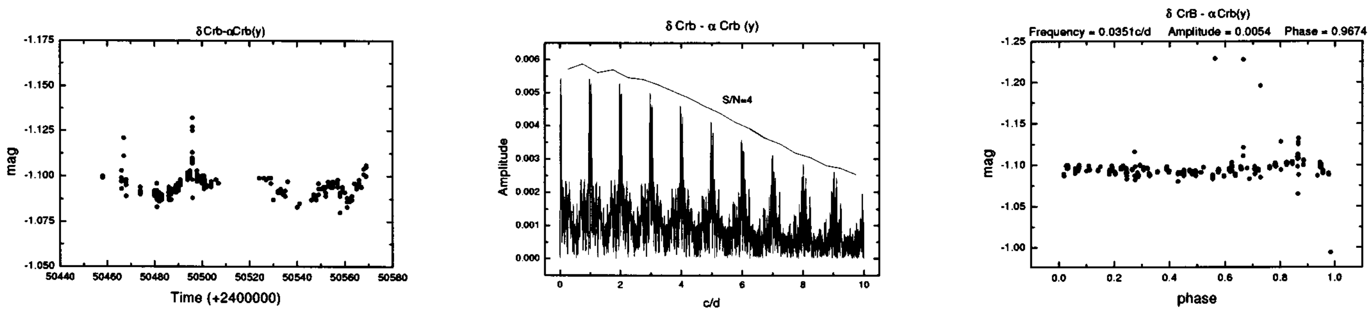

Fig. 35. δ CrB minus α CrB. Two (primary) eclipses are seen due to α CrB and a long-term 28-day variation due to δ CrB

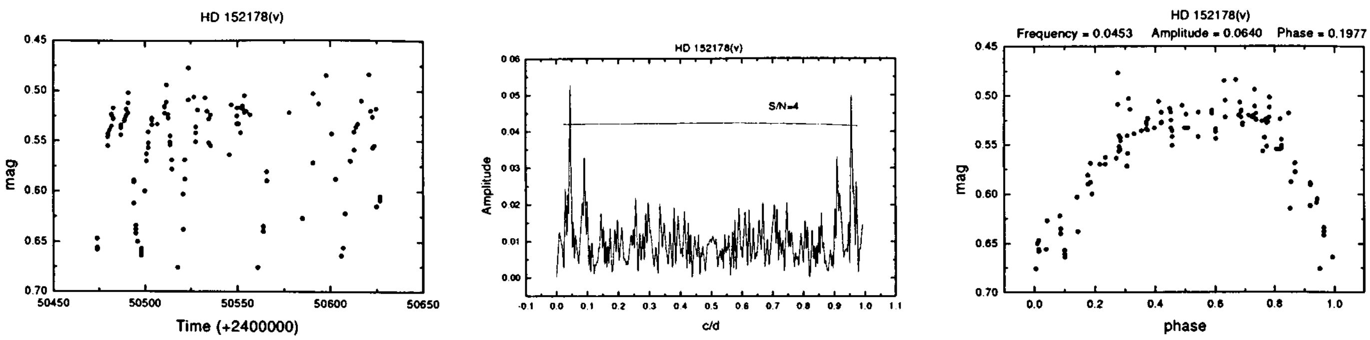

Fig. 36. As in Fig. 1 but for HD 152178

BD–08°3999 (UZ Lib). Recently, Fekel et al. (1999) presented a new orbit determination and summarized the star's fundamental properties. Strassmeier et al. (1997a) obtained a Doppler image of UZ Lib and we refer to their discussion for further relevant literature on this star. The 1996/97 season's photometry shows the star with a relatively small V amplitude of $0\overset{m}{.}1$ and a doubled-humped light-curve shape but confirms the 4.7-day period. Note that in this case the periodogram from sine-curve fitting gives smaller residuals at one half the true period. Figure 33 shows the light curves and the periodogram.

HD 139006 (α CrB). α CrB is a known eclipsing binary with a bright and dominating A0V primary and a comparably small G5V secondary with an orbital period of 17.4 days (Tomkin & Popper 1986). At X-ray wavelengths, the A star is not detected at all and Schmitt & Kürster (1993) used this fact to presented an image of the corona of the G5 secondary from X-ray eclipse mapping. Recently, Schmitt (1998) reported the discovery of apsidal motion in α CrB from X-ray eclipse timings. Our photometry during times outside eclipses indicates no variations above the nominal noise level. Two primary eclipses were covered and showed a depth of only $0\overset{m}{.}03$ in y. See Fig. 35 for an (inverse) light curve of the α CrB eclipses.

HD 140436 (γ CrB). This star was the comparison star in the α CrB group and turned out to be the suspected "Maia"-type variable γ CrB (Lehmann et al. 1997). The history of light variability for this bright ($V = 3\overset{m}{.}8$) star is checkered. Originally, the variability was discovered by Fernie (1969) and confirmed by Percy (1970) from a more extensive dataset that showed an amplitude of up to $0\overset{m}{.}05$ in V and B and a period of 0.03 days. Veto & Kovacs (1981) monitored γ CrB during four nights in 1981 but found no variability above 2–5 millimag. The recent "Catalog of variable stars in the lower instability strip" of Garcia et al. (1995) lists γ CrB as a variable with the parameters found by Percy (1970). In the course of the preparation of this paper, we learned that photometric variations were also detected by Scholz et al. (1998).

Our frequency analysis of the 1996/97 Wolfgang data shows the strongest reduction of the sum of the squared residuals at a period of 0.44534 days and with an amplitude of $0\overset{m}{.}010$ in b and $0\overset{m}{.}005$ in y. Note that the period from the y data (0.44543 days) is less significant due to the much smaller amplitude but is consistent with the b period. The periodogram from the b data in Fig. 34 shows a series of additional peaks above the $S/N = 4$ threshold but they are all aliases of the 0.445-day period ($f_0 = 2.24548$), including the $f_0 \pm 1$ periods of 0.8031 days and 0.3081 days. In a recent series of papers, Lehmann et al. (1997) detected radial-velocity variations of γ CrB with a period of 0.44499 days and concluded that twice this period, i.e. 0.89 days, is the fundamental period. They suggested that this must be the rotation period of γ CrB because a 0.445-day period would indicate a (less likely) very low inclination of the stellar rotation axis of $i \approx 20°$ and consequently the very high equatorial rotational velocity of 270 km s^{-1}. Two more periods were cited by Lehmann et al. (1997), i.e. 0.1271 days and 0.0989 days, but neither of them shows up in our photometric data. Because the

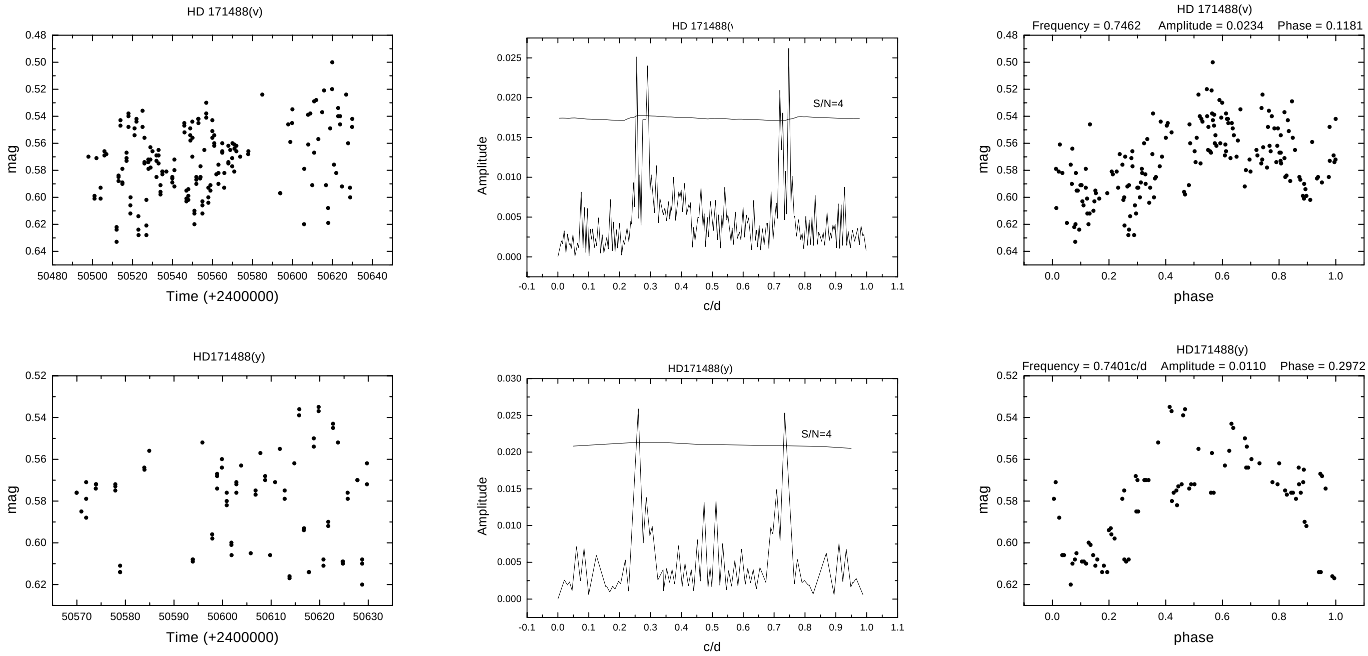

Fig. 37. As in Fig. 1 but for HD 171488. The upper three panels are data from Amadeus and show Johnson V, the lower panels are from Wolfgang and show Strömgren y

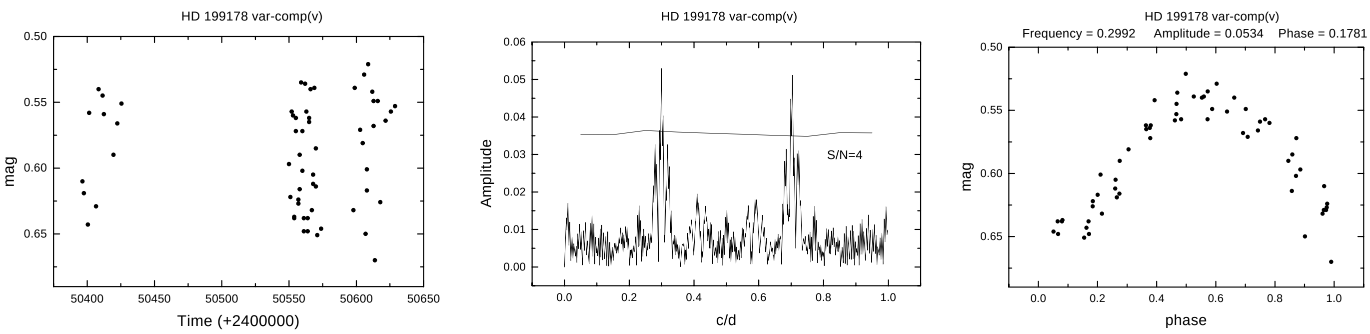

Fig. 38. As in Fig. 1 but for HD 199178

0.89-day period (i.e., $f_0/2$) is much weaker than the 0.445-day period in our data set, we conclude at the moment that the 0.44534-day period is the true period of γ CrB. The spectral classifications listed in SIMBAD are B9IV, A0IV, or A0V, which suggests that its light variability is most likely due to a combination of rapid rotation and non-radial pulsations, but that remains to be determined.

HD 141714 (δ CrB). δ CrB was chosen as the check star for the α CrB group and is a known chromospherically active, single, G5 giant (Baliunas 1987). Choi et al. (1995) determined its rotation period from Mt Wilson H&K-survey data as well as from broad-band photometry to 59 days, and thus confirmed the 60.8-day period found earlier by Fernie (1991). Unfortunately, our comparison star turned out to be a short-period variable (γ CrB, see above) and its variations are modulated into the δ CrB photometry. However, our actual target star, α CrB, is constant outside of eclipse and we use it as the comparison star for all differential magnitudes of δ CrB. Our period analysis of these data does not show the strongest peak at the anticipated 60-day period but at 28.5 days ($f = 0.0351$). Note that even visually the y-band light curve in Fig. 35 indicates this period and not a 60-day period. However, if the light curve appeared double-humped during the times of our observations, we would measure only one half of the true period. Therefore, we consider our true period to be $2 \times P_{\rm phtm} = 57$ days. Due to the small amplitude of just $0\overset{\rm m}{.}012$ in y, this period is uncertain by $\approx$4 days and is therefore still within the range of previous period determinations. Figure 35 shows our light curve and periodogram from 1996/97.

HD 152178 (V2253 Oph). Houk (1982) had noted the Ca II H & K emission of this SB1 binary. This prompted Strassmeier et al. (1993) to include it in the second edition of the catalog of chromospherically active binary stars. Later, the Ca II H & K emission was confirmed from high-resolution spectra by Strassmeier et al. (1994b). The light variability with a period of 22.35 days was discovered by

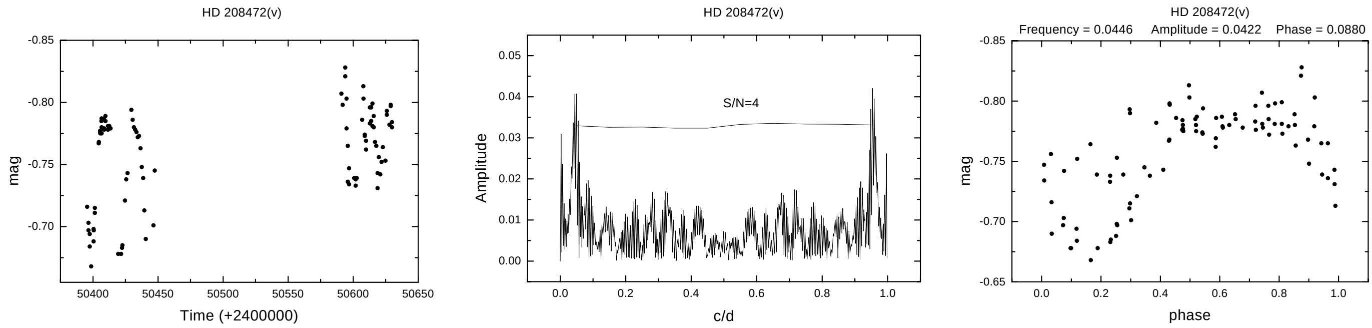

Fig. 39. As in Fig. 1 but for HD 208472

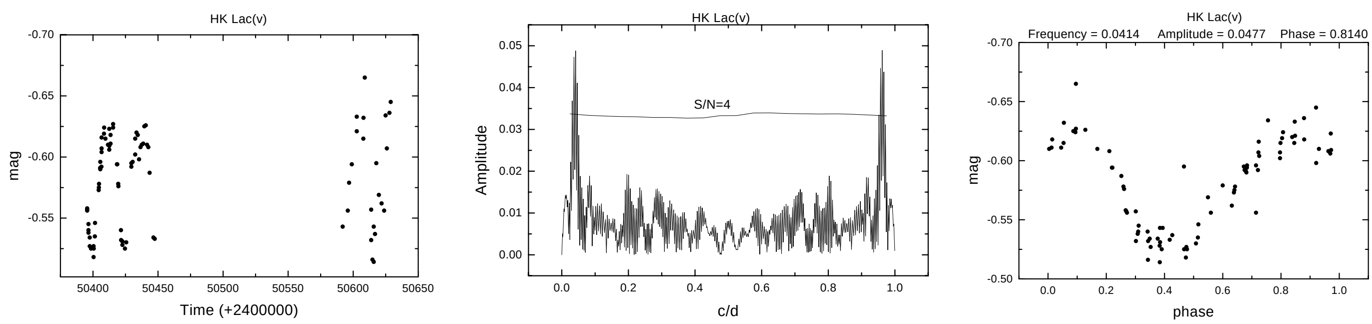

Fig. 40. As in Fig. 1 but for HK Lac

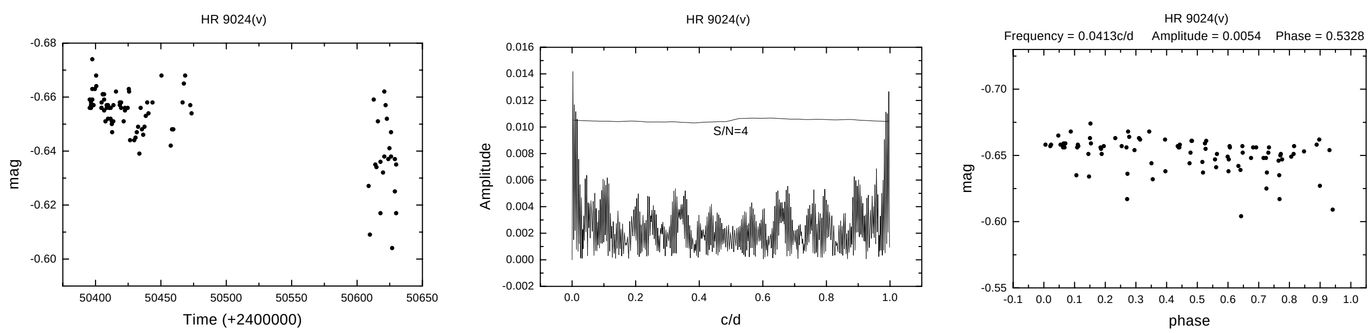

Fig. 41. As in Fig. 1 but for HR 9024

Hooten & Hall (1990) while Eaton et al. (1996) presented a V light curve from the full observing season 1989 to demonstrate the rapid decrease of its amplitude from $0^{\mathrm{m}}.2$ to $0^{\mathrm{m}}.05$ within 100 days. Fekel (1997) revised the projected rotational velocity from 24 to 28.8 km s^{-1} and, recently, Fekel et al. (1999) presented an orbit determination with an orbital period of 314.47 days. Our new data from 1996/97 were gathered with the Amadeus APT and showed a maximum amplitude of $0^{\mathrm{m}}.15$ in V. The periodogram in Fig. 36 is dominated by the many aliases of the one-day observing period but show the 22-day period as a significant frequency at 0.0453 c/d (22.07 days).

HD 171488 (V889 Her). Henry et al. (1995b) and Cutispoto et al. (1998) presented photometry for this G0V star and both groups independently found its light variations with an amplitude of $0^{\mathrm{m}}.1$ and a period of 1.338 days. Such a short period is also in agreement with the dwarf classification and the measured rotational velocity of 33 km s^{-1} (Henry et al. 1995b). For further references on this star, we refer the reader to the discussion in Henry et al. (1995b). Our 1996/97 season photometry was obtained with both Vienna APTs and showed HD 171488 with a quite variable light amplitude between $0^{\mathrm{m}}.1$ in mid March and $0^{\mathrm{m}}.01$ just 20 days later, and the same again in mid May (see Fig. 37). The seasonal average photometric period with the largest reduction of the χ^2 is 1.340 days ($f = 0.746$ c/d) in the Amadeus data set and $0^{\mathrm{d}}.792$ days ($f = 1.263$ c/d) in the Wolfgang data set. A frequency of 0.740 c/d is present in the Wolfgang data as well, as does the 1.263-c/d frequency in the Amadeus data, but both appear comparably weaker (see Fig. 37). The combined $V+y$ data show a 0.748-c/d frequency (1.337 days) as the highest peak (the y magnitudes were transformed to V using the relation in Olsen (1983). Therefore, we confirm the existence of the 1.34-day period but emphasize that there is a strong alias of 0.79-days in our data sets.

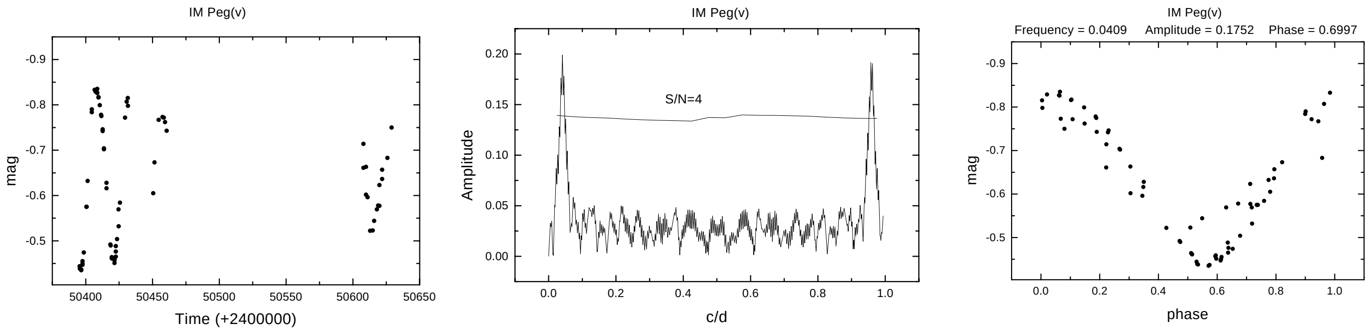

Fig. 42. As in Fig. 1 but for IM Peg

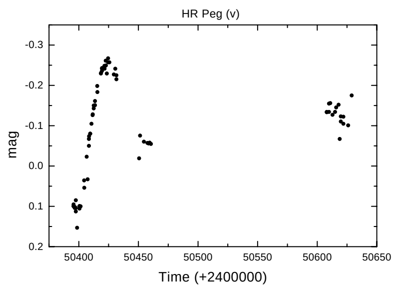

Fig. 43. Seasonal V light curve for the S-giant HR Peg

HD 199178 (V1794 Cyg). HD 199178 belongs to the FK Comae group of rapidly rotating single giants and has been the target of numerous investigations (see, e.g., Strassmeier et al. 1999a; Jetsu et al. 1993; Dempsey et al. 1992 and references therein). Most recently, Jetsu et al. (1999) reinvestigated all available UBV photometry up to 1996 and found unpredictable activity shifts that resulted in significantly different photometric periods from year to year and even within one year. These periods are between 3.81 and 3.14 days with an average of 3.3175 days. Our data from the observing season 1996/97 indicate a period of 3.342 days and an average amplitude of $0\overset{\mathrm{m}}{.}12$ in V. Note that our comparison-star magnitudes (SAO50313) were also transformed to Cousins $V(I)_{\mathrm{C}}$, and we found $V = 6\overset{\mathrm{m}}{.}649 \pm 0\overset{\mathrm{m}}{.}013$ and $I_{\mathrm{C}} = 5\overset{\mathrm{m}}{.}592 \pm 0\overset{\mathrm{m}}{.}016$ for SAO50313.

HD 208472 (V2075 Cyg). Henry et al. (1995b) discovered the light variability of this G8III giant and also found it to be a single-lined spectroscopic binary with an orbital period of 22.6 days. Recently, Fekel et al. (1999) presented an orbit determination and summarized the star's fundamental properties. The photometric period of 22.54 days suggests a synchronous rotator despite that the eccentricity of the orbit was not explicitely determined but must be very close to zero. Recently, Fekel (1997) revised his earlier $v \sin i$ determination from 21 to 19.7 km s^{-1}. Our new photometry was gathered with the Amadeus APT. While the amplitude was $0\overset{\mathrm{m}}{.}12$ in November 1996, it decreased to $0\overset{\mathrm{m}}{.}07$ in June 1997. Note that Henry et al. (1995b) had seen the star with an amplitude of $0\overset{\mathrm{m}}{.}36$ in V in 1993/94. Such large changes are typical for only the most active stars. The best-fit period from the Amadeus data was 22.42 ± 0.12 days.

HD 209813 (HK Lac). Oláh et al. (1997) presented and analysed 30 years of photoelectric observations of HK Lac and we refer the reader to the many references in that paper. Our new data from the 1996/97 observing season are from the Amadeus APT and showed a full $0\overset{\mathrm{m}}{.}1$ V amplitude in November/December 1996 which increased to $0\overset{\mathrm{m}}{.}15$ by June 1997. A shallow secondary minimum was seen at the beginning of the season (Fig. 40) but had vanished by June. The photometric period was 24.15 days in agreement with previous determinations and the orbital period.

HR 9024 (OU And). Hopkins et al. (1985) discovered the light variability of HR 9024 and determined a preliminary period of between 22–24 days. Cowley & Bidelman (1979) classified the spectrum as G1III and discovered the Ca II H & K emission. Several years of photometry were presented by Strassmeier & Hall (1988b) who found a photometric period of 22.6 days. Fekel et al. (1986) and Strassmeier et al. (1989) determined further relevant stellar parameters. HR 9024 was detected in the ROSAT all-sky survey by Huensch et al. (1998) which proved that HR 9024 is also coronally active. The photometric amplitude in 1996/97 amounted to barely $0\overset{\mathrm{m}}{.}01$ in V but revealed a declining trend towards the end of our observations in June 1997. The period from our data set is 24.2 days but is not well defined and accordingly uncertain. We note that the minimum radius of 9.6 $R_{\odot}$ from $v \sin i$ and the photometric period (Table 1) is in severe disagreement with the spectral classification of G1III. Unless the light curve of HR 9024 is double humped, and thus the true period twice as long as the one reported in this and previous papers, we recommend further monitoring of this bright star. Figure 41 shows the seasonal V light curve, the periodogram, and the phased V light curve.

HD 216489 (IM Peg). Previous APT data were analyzed in Strassmeier et al. (1997a) while Fekel et al. (1999) presented an orbit determination and also summarized the star's fundamental properties. For more details on IM Peg, we refer the reader to the discussions in these papers. The 1996/97 photometry showed the star with a large $0\overset{\mathrm{m}}{.}4$ V amplitude in November/December 1996 which declined to

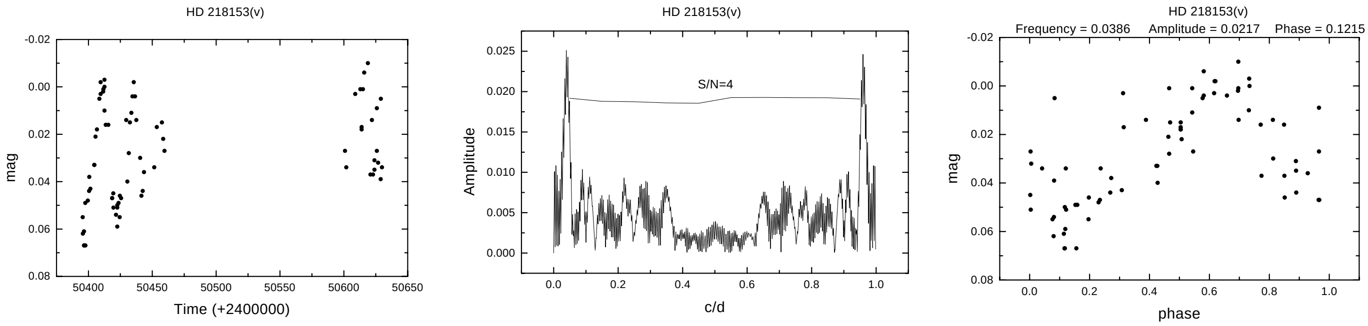

Fig. 44. As in Fig. 1 but for HD 218153

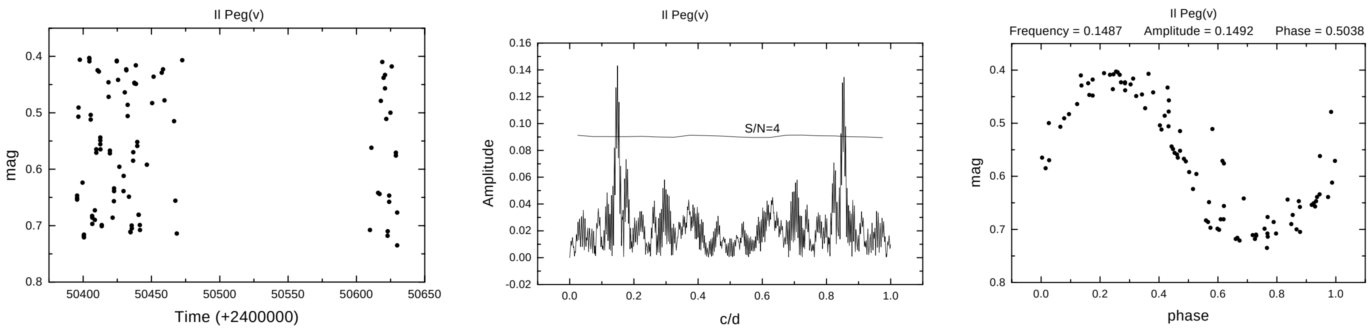

Fig. 45. As in Fig. 1 but for II Peg

approximately $0\overset{m}{.}22$ by June 1997. The photometric period was 24.45 days. Figure 42 shows the light curves and the periodogram from the V data.

HD 216672 (HR Peg). This was our check star for the Amadeus observations of IM Peg and is the semi-regular S-type giant HR Pegasii (= HR 8714, e.g. Eggen 1992) and, since our comparison star was proven to be constant, we present a seasonal light curve for HR Peg in Fig. 43.

HD 218153 (KU Peg). Weber et al. (1999) presented three Doppler images obtained from data from three consecutive rotations of the star in late 1996. Parts of our APT data were already used by them as additional input for the line profile inversion. Here, we present the complete dataset for the entire observing season 1996/97 and obtain a photometric period of 25.9 days.

HD 224085 (II Peg). Berdyugina et al. (1998a,1998b) presented Doppler images of II Peg and also updated the orbital and atmospheric parameters of this very active RS CVn binary and we refer the reader to that paper and the literature cited therein. Our new photometric data from 1996/97 show a period of 6.725 days, very close to the orbital period of 6.72433 days

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