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Study of FK Comae Berenices

IV. Active longitudes and the "flip-flop" phenomenon⋆,⋆⋆

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Abstract. Doppler imaging techniques have earlier been used to study the starspots and their evolution over a four year period in a single, late-type star FK Com. In the present work we publish new photometric observations of FK Com for the year 2001 and analyse them together with the previously published photometry obtained since 1966. These observations enable us to study the spot configuration on the stellar surface over much longer time period than the Doppler imaging alone permits, and so to look for possible activity cycles. The longitudinal spot configuration is recovered from the spot filling factor maps obtained with light curve inversion method. From the maps it is clear that the shape of the light curve is usually caused by one active region, which is often extended, and only occasionally by two regions. The spots tend to occur at two active longitudes which are 180° apart. These active longitudes are periodically active, i.e. the dominant part of the spot activity abruptly changes the longitude after about 3 years, indicating the "flip-flop" event. The full activity cycle is estimated to be 6.4 years. There is also clear evidence for migration of the active longitudes with at least three different rates. These rates correspond to the rotational periods of $2\overset{d}{.}40038 \pm 0\overset{d}{.}00009$ (for the years 1979–1993), $2\overset{d}{.}4030 \pm 0\overset{d}{.}0003$ (1994–1997) and $2\overset{d}{.}3960 \pm 0\overset{d}{.}0004$ (1997–2001). These periods are confirmed by using a more traditional time series analysis. The different migration rates of the active longitudes can be explained by weak solar-type differential rotation.

Key words. stars: activity – late-type – starspots – individual: FK Com

1. Introduction

FK Com is the prototype of the small group of FK Comae stars (Bopp & Stencel 1981). It is a single, extremely rapidly rotating, late type giant with $v \sin i = 162.5 \pm 3.5\,\mathrm{km\,s^{-1}}$ (Huenemoerder et al. 1993). The current estimates for the spectral type range from G2 III to G7 III (see, e.g. Bopp & Rucinski 1981; Walter & Basri 1982; Korhonen et al. 2000, from here-on Paper II; Korhonen et al. 2001a, from here-on Paper III). Small light curve variations, $\Delta V = 0\overset{m}{.}1$, with a period of $2\overset{d}{.}412$ were first reported by Chugainov (1966). These variations were later interpreted to be caused by asymmetrically distributed spots (Bopp & Rucinski 1981). Jetsu et al. (1991, 1993) reported that the active regions of FK Com show a "flip-flop" behaviour, in which the dominant part of the spot activity shifts 180° in longitude over a short period of time and remains at this new active longitude for some time. The full cycle of "flip-flops" was estimated from photometric observations to be 6.5 years by Korhonen et al. (1999, from here-on Paper I). Since Jetsu et al. (1991) discovered "flip-flops" in FK Com they have been detected also in some RS CVn binaries (e.g. Berdyugina & Tuominen 1998; Berdyugina et al. 1999).

The first surface map of FK Com using Doppler imaging was obtained by Piskunov et al. (1994) for the year 1989. Their results show low-contrast cool photospheric spots near the equator and some high latitude He I D_3 emission. The next Doppler imaging maps of FK Com were obtained for the years 1994 and 1995 (Paper I), for the years 1996 and 1997 (Paper II) and for January 1998 (Korhonen et al. 2001b). These maps mainly show high latitude spots and no clear polar spots. The images for the years 1994–1997 showed that the long-lived spot group migrated on average 0.22 ± 0.03 in phase within a year (Paper II). This migration was most likely caused by a difference between the photometric period used in the calculations (25 year average period from Jetsu et al. 1994a), $2\overset{d}{.}4002466 \pm 0\overset{d}{.}0000056$, and the real spot rotation period for

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⋆ Based on the observations obtained at Phoenix 10, Arizona, USA; Wolfgang and Amadeus, Arizona, USA; Mount Maidanak Observatory, Uzbekistan; La Palma KVA 0.6 m Cassegrain telescope, La Palma, Spain.

⋆⋆ Table 1 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb-u-strasbg.fr/cgi-bin/qcat?J/A+A/390/179

1994–1997, $2\overset{d}{.}4037 \pm 0\overset{d}{.}0005$ (Paper II). This migration rate was confirmed to be present also during the autumn 1997 (Korhonen et al. 2001b). The maps from 1994–1997 were also used for studying possible surface differential rotation. No evidence for it could be found from temperature maps separated by 30 days, 72 days and about a year (Paper II).

In Paper III all previously published photometric observations for the years 1966–1997 were analysed together with new observations from 1993–2001. The period analysis of maximum, mean and minimum magnitudes and the peak-to-peak variation of the V magnitude from individual observing seasons, spanning 35 years, showed two dominant types of cycles: with long periods around 12, 14 and 31 years and with short periods about 3 and 6 years. The longest period found seemed to correspond to the cycle of the total minimum-maximum variation from 1970's to early 1990's, and therefore, indicates the time scale of the total spottedness variation. The shortest periods most likely corresponded to the cycle of "flip-flops".

In this paper new photometric observations from the year 2001 are published and the analysis of the photometry of FK Com is continued, the main aim being the investigation of the active longitudes and the "flip-flop" phenomenon. The individual light curves covering the 35 year period are converted with the inversion method into surface maps of the longitudinal spot distribution at different times. The observations since 1979 are numerous enough to study in detail the active longitudes and the cyclic shifting of the activity between these two longitudes.

2. Observations

Most of the observations used in this article have been collected and published earlier by Jetsu et al. (1994a, 1994b, and references therein), Strassmeier et al. (1997) and Paper III. For the year 2001 new automatic photometric telescope observations are published electronically (Table 1). The new observations have been obtained between 30th of December 2000 and 28th of December 2001 using the Phoenix 10 telescope, Arizona, USA. There are 148 U, 181 B and 184 V observations which were obtained and reduced in the same way as described in Paper III.

For the purpose of the light curve inversions the observations were divided into 52 sets based on the phase coverage over the rotation period and the stability of the light curve during that time. The ephemeris from Jetsu et al. (1993),

$$\mathrm{HJD} = 2439252.895 + 2\overset{d}{.}4002466E, \quad (1)$$

was used for calculating the phases throughout this paper. The V-band measurements were chosen for the inversions, since they make up the largest amount of data.

3. Light curve inversions

The individual light curves have been inverted in order to investigate the spot position and evolution during the 35 years. Light curves represent one-dimensional time-series, so only the longitudinal information can be recovered from them, but that is enough for investigation of the possible active longitudes and the "flip-flop" phenomenon.

The inversions were done by using the Occamian approach inversion method (Berdyugina 1998). In the inversions the stellar surface was divided into a grid of $10^\circ \times 10^\circ$. The temperatures for the unspotted surface and the spots were fixed to 5000 K and 4000 K, respectively, based on the earlier results obtained with Doppler imaging (Papers I and II). The limb-darkening coefficient in the V-band for the temperature of the unspotted surface was estimated to be 0.717 from the results by Al-Naimiy (1978). For the sake of simplicity, the same value was also adopted for spotted areas. The brightest observed magnitude of FK Com is $8\overset{m}{.}03$ (Paper III), leading to the fixed unspotted magnitude of $8\overset{m}{.}0$.

A light curve inversion results in a specific distribution of the spot filling factor on the stellar surface, which can then be plotted to produce a map of the longitudinal spot distribution on the stellar surface at a given time. More details on the method can be found in Berdyugina et al. (2002).

The results of inversions for the 52 individual light curves between 1966–2001 are presented in Fig. 1 together with the light curves themselves. As can be seen, the maps usually show only one active region which often is extended. A secondary spot is also sometimes seen. Doppler images of FK Com which are based on inversions from spectroscopic observations for 1994–1997 (Papers I and II; Korhonen et al. 2001b) reveal that the extended active region in the light curve inversions consists of two separate spots. At least this is true for the light curve inversion results for the time periods of 1994.60, 1995.36, 1996.37, 1997.12, 1997.38 and 1997.95, for which we have maps obtained with Doppler imaging. The comparison between the Doppler images and the results from the light curve inversions reveals that the resulting maps are very similar in the longitudinal position of the spots, except that the Doppler images give more detailed information on the spot configuration itself.

4. Activity patterns of FK Com

4.1. Light curve evolution

The peak-to-peak variation of the light curve in V-band is on average $\Delta V \approx 0\overset{m}{.}15$, but there are periods when it is much smaller than that. For the years 1998 and 1999 the variation was all the time around $0\overset{m}{.}1$ going to as low as $0\overset{m}{.}05$ in December 1998 (1998.96), indicating an almost uniform spot distribution over the stellar surface. For the spring 1999 (1999.31) the light curve has less features than in the December 1998, but the scatter in the observations is larger, so the peak-to-peak variation also becomes larger ($0\overset{m}{.}07$). The largest variation in the light curve occurs during the spring 1995 (1995.36), being $\Delta V = 0\overset{m}{.}27$ and suggesting the spots to be concentrated on one stellar hemisphere.

Usually, the shape of the light curve is stable for a long period of time, sometimes even for one and half years, e.g. 1987–1988, but there is also evidence for very rapid changes in the light curve. The most pronounced example is from the summer 1999, where the light curve in June

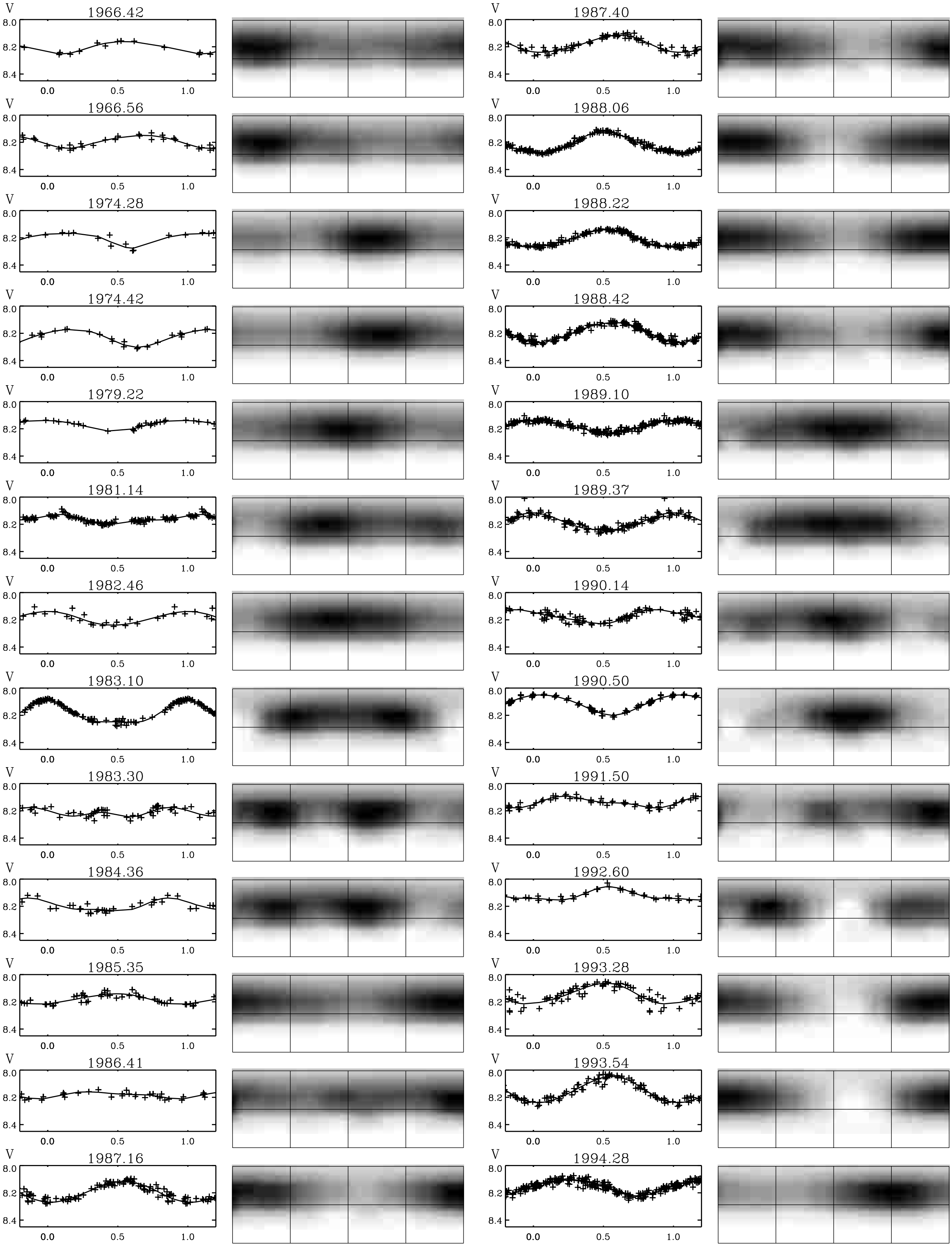

Fig. 1. The results from the light curve inversion in grey-scale, where darker regions indicate larger spot filling factor. The grid in the maps indicates the equator and 4 longitudes separated by 90°. The phases for the observed (crosses) and calculated (line) *V* light curves have been calculated from Eq. (1).

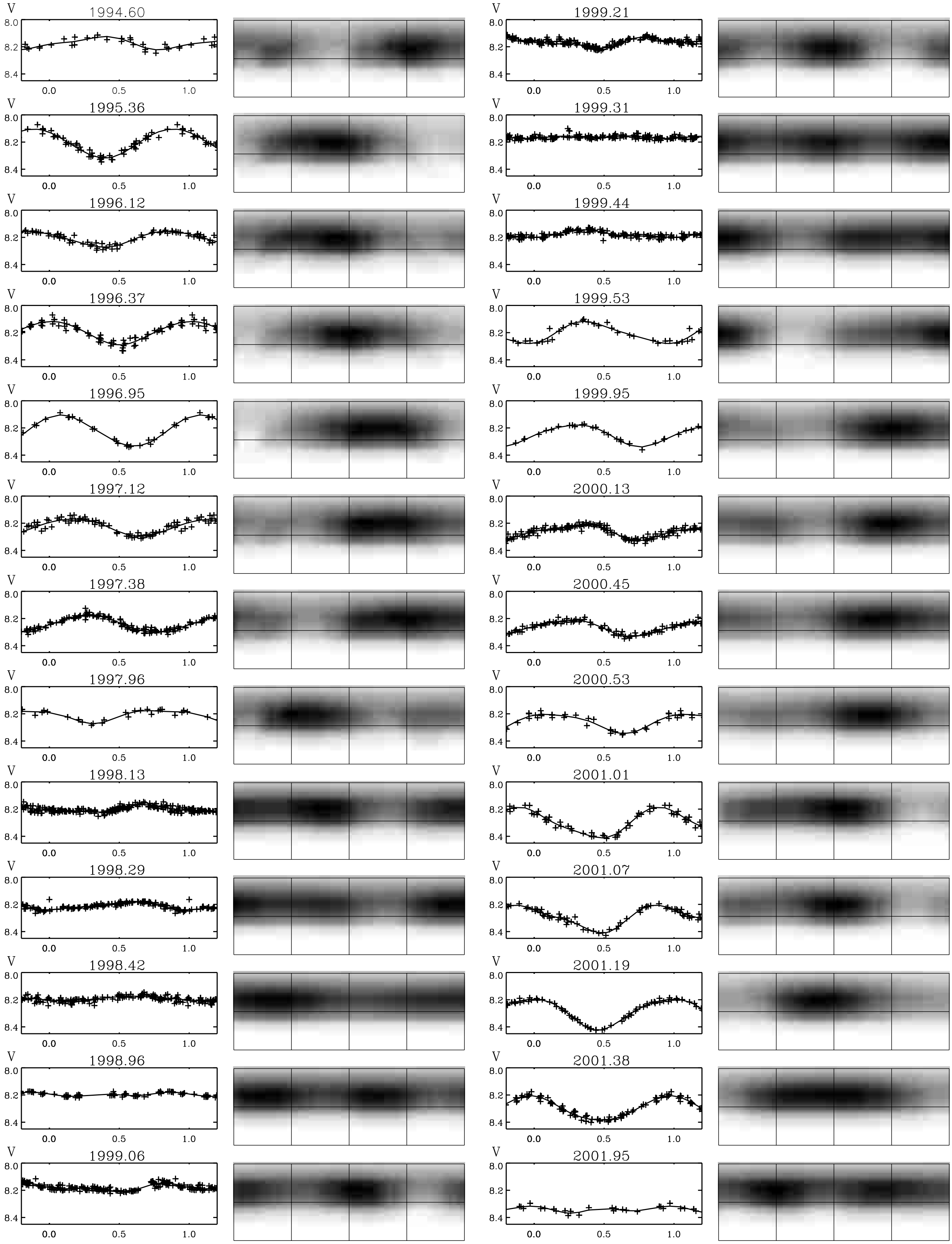

Fig. 1. continued.

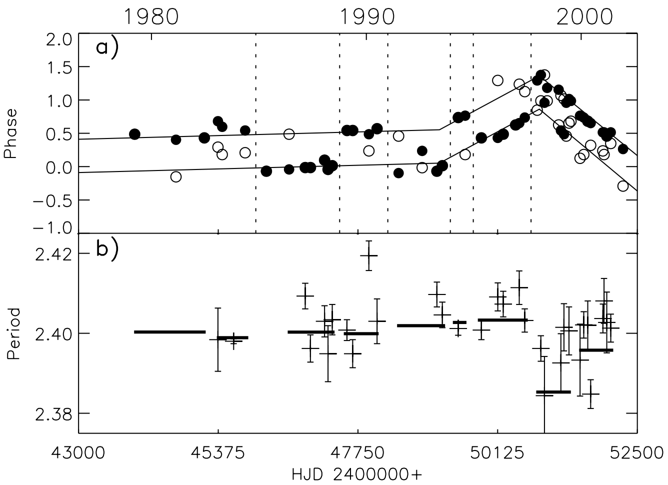

Fig. 2. a) Phases of spots determined from the light curve inversions plotted versus Julian days for the years 1979–2001. Filled circles denote larger spots and open circles secondary spots. The active longitudes (0.5 in phase apart) are presented with solid lines and the times of the "flip-flops" with dashed lines. **b)** Periods determined from individual light-curves with their errors (crosses with vertical error-bars) and periods determined from all the data in between the "flip-flops" (thick horizontal solid lines).

is basically flat with $\Delta V = 0\overset{\mathrm{m}}{.}09$, but the July light curve already shows much more variation, $\Delta V = 0\overset{\mathrm{m}}{.}18$. The time difference between these light curves is on average 33 days (the July observations start when the June observations end). The light curve inversion shows that this change in the light curve was caused by two spots that moved closer and finally formed one stronger active region. Another example of rapid light curve evolution is from 1983, where the peak-to-peak variation changes from $0\overset{\mathrm{m}}{.}20$ to $0\overset{\mathrm{m}}{.}11$ in on average 87 days. This time the change in the light curve was caused by two spots that moved apart.

4.2. Active longitudes

In order to recognize active longitudes in FK Com, we measured positions of spots at phases of the maximum spot filling factor. Phases of both the primary and the secondary spots, when present, were determined. In Fig. 2a phases of spots are plotted against Julian days for the years 1979–2001. The measured phases together with the year and the time for the light curve minimum are listed in Table 2.

As can be seen, the concentrated part of the spot activity in FK Com tends to occur at two longitudes separated by 180°, as was first revealed by Jetsu et al. (1991) and later confirmed by our Doppler imaging results. The recognition of the active longitudes before 1984 is difficult, because the photometric observations are sparse, and also in 1982–1984 a bigger active region splits into two spots which then drift apart.

The active longitudes seem to rotate with different periods in 3 different time intervals (Fig. 2): 1979–1992, 1993–1998, 1998–2001. For determining the rotation periods of the active longitudes, a linear fit was applied to phases of the spots that approximately moved with the same rate (Fig. 2a). This was done simultaneously for both active longitudes. From the slopes of the fits the periods corresponding to the rotation rates were calculated. The three periods are presented in Table 3.

For checking the reality of these periods, period search was also done using Irregularly Spaced Data Analysis Package (ISDA, Pelt 1992). The periods were determined from the individual light curves (as presented in Fig. 1) and also for all the data obtained in between two "flip-flops" indicated by vertical dashed lines in Fig. 2a. In ISDA the automatic mode which chooses the fastest computational scheme was used. The periods from individual light curves are plotted with the error bars in Fig. 2b together with the periods determined from the data in between the "flip-flops" (thick horizontal lines). Sometimes individual light curves showed too small variations or the data were too sparse for the period search to work, but for most light curves the period was found.

All the periods determined with different methods (slope of the active longitudes, period search with ISDA and from Doppler imaging in Paper II) are listed in Table 3. The results are very similar: the period is almost constant for 1979–1990, starting to gradually get longer for 1991–1997, after which the period becomes again significantly shorter. This behaviour is also easily seen in the slopes of the active longitudes presented in Fig. 2a.

Two active longitudes have been also detected in RS CVn binaries (e.g. Jetsu 1996; Berdyugina & Tuominen 1998). For one of them an oscillating migration rate along the activity cycle has been reported by Rodonò et al. (2000). Cyclic variations of the rotation period of the active longitudes have been detected in a single dwarf LQ Hya (Berdyugina et al. 2002). The possibility of active longitudes has been also investigated in another FK Comae star, V1794 Cyg (HD 199178), by Jetsu et al. (1999). They did not find any clear evidence for active longitudes, but reported continuous migration of the long-lived activity centers and a strong possibility of surface differential rotation.

4.3. "Flip-flop" phenomenon

The whole sequence of the light curve inversion maps since 1966 (Fig. 1) shows that sometimes an abrupt change of 180° in the longitudinal spot position occurs, e.g. between the summer 1988 and winter 1989. This is the so-called "flip-flop" phenomenon. Such events are easy to see in Fig. 2a where they are marked with dashed vertical lines at the moments when the dominant part of the spot activity abruptly changes the active longitude. Between 1979 and 2001 at least six such changes can be detected with an average period of 3.2 years. This means that the whole cycle during which the activity returns to the same longitude is 6.4 years. These values are comparable to the periods of 3 and 6 years found from the analysis of the photometry from the 35 years (Paper III) and also to the cycle of 6.5 years estimated in Paper I. An anomalously short "flip-flop" happened in the year 1994, when the activity stayed at the same active longitude only for 1.1 years. Another short event can be seen during the early 1999. Anyhow, during this time both active longitudes are similarly active, which means that this is not really a "flip-flop".

Table 2. Phases of main spots (spot_1) and secondary spots (spot_2) together with average times of the observations in years and Julian days for the light curve minima (JD_1 and JD_2).

Year	spot_1	JD_1 (2400000+)	spot_2	JD_2 (2400000+)	Year	spot_1	HJD_1 (2400000+)	spot_2	HJD_2 (2400000+)
1979.22	0.486	43 953.7439			1996.12	0.431	50 127.0462	1.292	50 129.1128
1981.14	0.403	44 656.8170	−0.153	44 655.4824	1996.37	0.486	50 220.7879		
1982.46	0.431	45 139.3338			1996.95	0.625	50 429.9429		
1983.10	0.681	45 370.3575	0.292	45 369.4238	1997.12	0.653	50 492.4166	1.236	50 493.8159
1983.30	0.597	45 442.1633	0.181	45 441.1648	1997.38	0.736	50 586.2254	1.125	50 587.1591
1984.36	0.542	45 833.2715	0.208	45 832.4698	1997.96	1.292	50 798.7816	0.847	50 797.7135
1985.35	−0.069	46 191.8419			1998.13	1.375	50 861.3873	0.986	50 860.4536
1986.41	−0.042	46 578.3464	0.486	46 579.6137	1998.29	0.958	50 922.7928	1.375	50 923.7937
1987.16	−0.014	46 852.0417			1998.42	1.181	50 968.9327	0.986	50 968.4647
1987.40	−0.014	46 940.8509			1998.96	1.153	51 163.2855	0.625	51 162.0182
1988.06	0.097	47 181.1419			1999.06	0.542	51 200.2229	1.069	51 201.4878
1988.22	−0.042	47 240.8145			1999.21	0.486	51 252.8939	1.014	51 254.1612
1988.42	0.014	47 312.9563			1999.31	0.958	51 292.4308	0.458	51 291.2306
1989.10	0.542	47 563.8493			1999.44	1.014	51 340.5701	0.653	51 339.7036
1989.37	0.542	47 659.8591			1999.53	0.986	51 371.7061	0.681	51 370.9740
1990.14	0.486	47 935.7531	0.236	47 935.1530	1999.95	0.764	51 527.1893	0.125	51 525.6555
1990.50	0.569	48 075.1666			2000.13	0.736	51 589.5285	0.181	51 588.1964
1991.50	−0.097	48 440.8058	0.458	48 442.1379	2000.45	0.681	51 656.6034		
1992.60	0.236	48 840.0460	−0.015	48 839.4428	2000.53	0.653	51 706.9414	0.319	51 706.1397
1993.28	−0.069	49 091.3398			2001.01	0.514	51 913.0289	0.236	51 912.3617
1993.54	0.014	49 185.1486			2001.07	0.514	51 934.6312	0.181	51 933.8319
1994.28	0.736	49 455.7092			2001.19	0.458	51 980.1014		
1994.60	0.764	49 573.3885	0.181	49 571.9892	2001.38	0.514	52 047.4427	0.347	52 047.0419
1995.36	0.431	49 848.6176			2001.95	0.264	52 255.6641	−0.292	52 254.3296

Table 3. The periods for different years from ISDA, fits to the active longitudes (Fig. 1) and Doppler Imaging (Paper II).

Years	ISDA	Fits to active longitudes
1979–1982	$2\overset{\mathrm{d}}{.}40032 \pm 0\overset{\mathrm{d}}{.}00024$	
1983–1984	$2\overset{\mathrm{d}}{.}3989 \pm 0\overset{\mathrm{d}}{.}0005$	
1986–1988	$2\overset{\mathrm{d}}{.}4003 \pm 0\overset{\mathrm{d}}{.}0005$	$2\overset{\mathrm{d}}{.}40038 \pm 0\overset{\mathrm{d}}{.}00009$
1989–1990	$2\overset{\mathrm{d}}{.}3999 \pm 0\overset{\mathrm{d}}{.}0005$	
1991–1993	$2\overset{\mathrm{d}}{.}40191 \pm 0\overset{\mathrm{d}}{.}00035$	
1994	$2\overset{\mathrm{d}}{.}4027 \pm 0\overset{\mathrm{d}}{.}0013$	$2\overset{\mathrm{d}}{.}4030 \pm 0\overset{\mathrm{d}}{.}0003$*
1995–1997	$2\overset{\mathrm{d}}{.}4033 \pm 0\overset{\mathrm{d}}{.}0003$	
1998–July 1999	$2\overset{\mathrm{d}}{.}38531 \pm 0\overset{\mathrm{d}}{.}00047$	$2\overset{\mathrm{d}}{.}3960 \pm 0\overset{\mathrm{d}}{.}0004$
Dec 1999–2002	$2\overset{\mathrm{d}}{.}39577 \pm 0\overset{\mathrm{d}}{.}0005$	

* The period from Doppler imaging is $2\overset{\mathrm{d}}{.}4037 \pm 0\overset{\mathrm{d}}{.}0005$.

Korhonen et al. (2001b) confirmed that the latest switch of the activity happened during the late 1997. The last light curve inversion map (2001.96) shows two active regions which are about 180° apart. The old active region (at about phase 0.25) is still the dominant one, but the new active region has already almost the same strength. This indicates that a new “flip-flop” will most likely happen during the early part of 2002. As can be seen from the maps for the early 1998, changing the strength of the active region in FK Com can happen very fast.

4.4. Evidence for differential rotation?

The period variations seen in FK Com can be interpreted with differential rotation and changing the spot latitude. When looking at the spot distribution in the Doppler images (Paper II and Korhonen et al. 2001b) it can be seen that the spots on average appear at the latitude 57° and that for the years 1994–1997 the spots occurred on average at higher latitudes (63°) than for the late 1997 and early 1998 (latitude 52°). Combining the latitude information obtained from the Doppler images and the rotational periods from the fits to the active longitudes (Table 3), the differential rotation rate can be estimated by using the $\sin^2 \psi$ law for the latitude dependence of the angular velocity. This gives $\alpha \approx 0.016$, where α is the ratio of the difference between the equatorial and polar angular velocities and the equatorial angular velocity. Extrapolation to the equator suggests the equatorial rotation period (P_{eq}) to be $2\overset{\mathrm{d}}{.}3721$. This result means weak solar-type differential rotation (for the Sun $\alpha = 0.19$) and is comparable to the results obtained for RS CVn binaries and young stars using either photometric data or Doppler imaging (see e.g., Henry et al. 1995; Donati & Collier Cameron 1997;

Messina et al. 1999; Barnes et al. 2000; Rodonò et al. 2000; Weber & Strassmeier 2001)

Note that the present estimate of the differential rotation for FK Com does not contradict the analysis of the Doppler images for the years 1994–1997 carried out in Paper II. We did not find significant differential rotation for the years 1994–1997 as the spots were observed at similar latitudes and were rotating with the same period. It was only the map from June 1997, that showed spots at different latitudes, but the time difference between the April 1997 and June 1997 maps is only 72 days making the accurate determination of the shift of the active region difficult.

5. Conclusions

From the analysis of the 52 light curve inversion maps based on the 35 years of photometric observations of FK Com we obtain the following results:

- The shape of the light curve is usually caused by one extended active region on the stellar surface. Our earlier Doppler images reveal that the extended region seen in the light curve inversions is actually two close-by spots, at least this is true for the years 1994–1997.
- The individual light curves in FK Com have an average peak-to-peak variation of $\Delta V \approx 0\overset{\mathrm{m}}{.}15$, the actual change being between $\Delta V = 0\overset{\mathrm{m}}{.}05$ and $\Delta V = 0\overset{\mathrm{m}}{.}27$.
- Usually the shape and amplitude of the light curve is stable for a long period of time, even for one and half years. Occasionally the changes in the light curve are very rapid, e.g. during the summer 1999 the peak-to-peak variation changed from $\Delta V = 0\overset{\mathrm{m}}{.}09$ to $\Delta V = 0\overset{\mathrm{m}}{.}18$ in 33 days.
- The main part of the spot activity in FK Com occurs at two active longitudes which rotate with three different rates during the years 1979–2001, corresponding to the periods of $2\overset{\mathrm{d}}{.}40038 \pm 0\overset{\mathrm{d}}{.}00009$ (for the years 1979–1993), $2\overset{\mathrm{d}}{.}4030 \pm 0\overset{\mathrm{d}}{.}0003$ (1994–1997) and $2\overset{\mathrm{d}}{.}3960 \pm 0\overset{\mathrm{d}}{.}0004$ (1997–2001).
- The dominant part of the spot activity changes the active longitude over the cycle of 6.4 years, averaged from the six detected "flip-flops" during 1979–2001. A new "flip-flop" will most likely happen early 2002.
- The period variation can be explained by differential rotation with the parameters $P_{eq} = 2\overset{\mathrm{d}}{.}3721$ and $\alpha \approx 0.016$, where α is the ratio of the difference between the equatorial and polar angular velocities and the equatorial angular velocity.

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References

Al-Naimiy, H. M. 1978, ApSS, 53, 181
Barnes, J. R., Collier Cameron, A., James, D. J., & Donati, J.-F. 2000, MNRAS, 314, 162
Berdyugina, S. V. 1998, A&A, 338, 97
Berdyugina, S. V., & Tuominen, I. 1998, A&A, 336, L25
Berdyugina, S. V., Berdyugin, A. V., Ilyin, I., & Tuominen, I. 1999, A&A, 350, 626
Berdyugina, S. V., Pelt, J., & Tuominen, I. 2002, A&A, submitted
Bopp, B. W., & Rucinski, S. M. 1981, in Fundamental Problems in the Theory of Stellar Evolution, ed. D. Sugimoto, D. G. Lamb, & D. N. Schramm (Reidel, Dordrecht), IAU Symp., 93, 177
Bopp, B. W., & Stencel, R. E. 1981, ApJ, 247, L131
Chugainov, P. F. 1966, Inf. Bull. Var. Stars, 172
Donati, J.-F., & Collier Cameron, A. 1997, MNRAS, 291, 1
Henry, G. W., Eaton, J. A., Hamer, J., & Hall, D. S. 1995, ApJS, 97, 513
Huenemoerder, D. P., Ramsey, L. W., Buzasi, D. L., & Nations, H. L. 1993, ApJ, 404, 316
Jetsu, L., Pelt, J., Tuominen, I., & Nations, H. L. 1991, in The Sun and Cool Stars: Activity, magnetism, dynamos, ed. I. Tuominen, D. Moss , & G. Rüdiger (Springer, Heidelberg), Proc. IAU Coll., 130, 381
Jetsu, L., Pelt, J., & Tuominen, I. 1993, A&A, 278, 449
Jetsu, L., Tuominen, I., Antov, A., et al. 1994a, A&AS, 103, 183
Jetsu, L., Tuominen, I., Grankin, K. N., Mel'nikov, S. Yu., & Shevchenko, V. S. 1994b, A&A, 282, L9
Jetsu, L. 1996, A&A, 314, 153
Jetsu, L., Pelt, J., & Tuominen, I. 1999, A&A, 351, 212
Korhonen, H., Berdyugina, S. V., Hackman, T., et al. 1999, A&A, 346, 101 (Paper I)
Korhonen, H., Berdyugina, S. V., Hackman, T., Strassmeier, K. G., & Tuominen, I. 2000, A&A, 360, 1067 (Paper II)
Korhonen, H., Berdyugina, S. V., Tuominen, I., et al. 2001a, A&A, 374, 1049 (Paper III)
Korhonen, H., Berdyugina, S. V., Strassmeier, K. G., & Tuominen, I. 2001b, A&A, 379, L30
Messina, S., Guinan, E. F., Lanza, A. F., & Ambruster, C. 1999, A&A, 347, 249
Pelt, J. 1992, Irregularly Spaced Data Analysis: User Manual (Helsinki University Press, Helsinki)
Piskunov, N. E., Huenemoerder, D. P., & Saar, S. H. 1994, in Proceedings of the Eighth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ed. J. P. Caillault, ASPC, 64, 658
Rodonò, M., Messina, S., Lanza, A. F., Cutispoto, G., & Teriaca, L. 2000, A&A, 358, 624
Strassmeier, K. G., Bartus, J., Cutispoto, G., & Rodonò, M. 1997, A&AS, 125, 11
Walter, F. M., & Basri, G. S. 1982, ApJ, 260, 735
Weber, M., & Strassmeier, K. G. 2001, A&A, 373, 974