RevMexAA (Serie de Conferencias), **36**, CD323–CD327 (2009)

SPOT EVOLUTION AND ACTIVE LONGITUDES ON FK COM: MORE THAN A DECADE OF DETAILED SURFACE MAPPING

H. Korhonen,[1] S. V. Berdyugina,[2] I. V. Ilyin,[3] K. G. Strassmeier,[3] and T. Hackman[4]

RESUMEN

Mapas de la superficie estelar pueden ser obtenidos de espectros de alta señal a ruido con alta resolución, usando técnicas de imagen Doppler. En este trabajo presentamos nuevos mapas de la superficie de la estrella gigante FK Com en 2004–2007, y los combinamos con nuestros mapas anteriores. Junto con las observaciones fotométricas esta serie de tiempo, única en su clase, es usada para estudiar la evolución de manchas y los tiempos de vida de dichas manchas, así como posibles longitudes activas en FK Com.

ABSTRACT

Stellar surface maps can be obtained from high resolution, high signal-to-noise spectra using Doppler imaging techniques. In this work we present new surface temperature maps of the giant FK Com for 2004–2007, and combine them with our earlier maps. The detailed images of the stellar surface span now almost 15 years. Together with the photometric observations this unique time series is used to study the spot evolution, spot life times, and possible permanent active longitudes on FK Com.

Key Words: stars: activity — stars: individual (FK Com) — stars: late-type — stars: spots

1. INTRODUCTION

FK Comae stars are a small group of magnetically very active late-type giants with rotation periods of only a few days. The photometric and spectroscopic characteristics of FK Comae stars are very similar to those of the very active RS CVn stars, with the exception that RS CVn stars are close binary systems in which the tidal effects produce synchronous rotation, and therefore also rapid rotation.

FK Com itself with its $v \sin i$ of 160 km s^{-1} is the fastest rotator of the FK Comae stars, and thus also the most active of them. The spectrum of FK Com was first described by Merrill (1948). He noted a large projected rotational velocity, Hα and Ca II H&K emission and the variability of the Hα profile. Small visual brightness variations in FK Com of $\sim$ 0.1 mag in the V-band with a period of 2.412 days were first reported by Chugainov (1966). The amplitude of these variations can reach 0.3 mag at times. These variations are interpreted to be caused by large starspots on the surface of FK Com. Several surface temperature maps of FK Com have been obtained over the years using Doppler imaging techniques (see, e.g., Korhonen et al. 1999, 2007). These surface temperature maps show mainly high latitude spots with temperatures of approximately 1000 K lower than that of the unspotted surface.

Long-term photometric observations show that the spots on FK Com tend to concentrate on two active longitudes which are about 180° apart (Jetsu et al. 1993). These active longitudes are alternatively more active, and the main part of the spot activity changes the longitude every few years. The cycle length of this so-called flip-flop phenomenon has been determined to be 6.4 years (Korhonen et al. 2002), i.e., one flip-flop on average every 3.2 years. After its discovery in FK Com the flip-flop phenomenon has also been discovered in RS CVn binaries and young solar type stars (see e.g., Berdyugina & Tuominen 1998; Järvinen et al. 2005).

Here, we present new surface temperature maps obtained from high resolution spectra, and spot filling factor maps obtained from V band photometric observations of FK Com for the years 2004–2007. These data are used to further study the active longitudes and flip-flops on FK Com.

2. DOPPLER IMAGES

Doppler imaging is a method that can be used for detailed mapping of the stellar surface structure (e.g., Vogt et al. 1987; Piskunov et al. 1990).

[1]European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748, Garching bei München, Germany (hkorhone@eso.org).

[2]Institute of Astronomy, ETH Zurich, CH-8092 Zurich, Switzerland (sveta@astro.phys.ethz.ch).

[3]Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14882 Potsdam, Germany (ilyin@aip.de, kstrassmeier@aip.de).

[4]Observatory, PO Box 14, FI-00014 University of Helsinki, Finland (Thomas.Hackman@helsinki.fi).

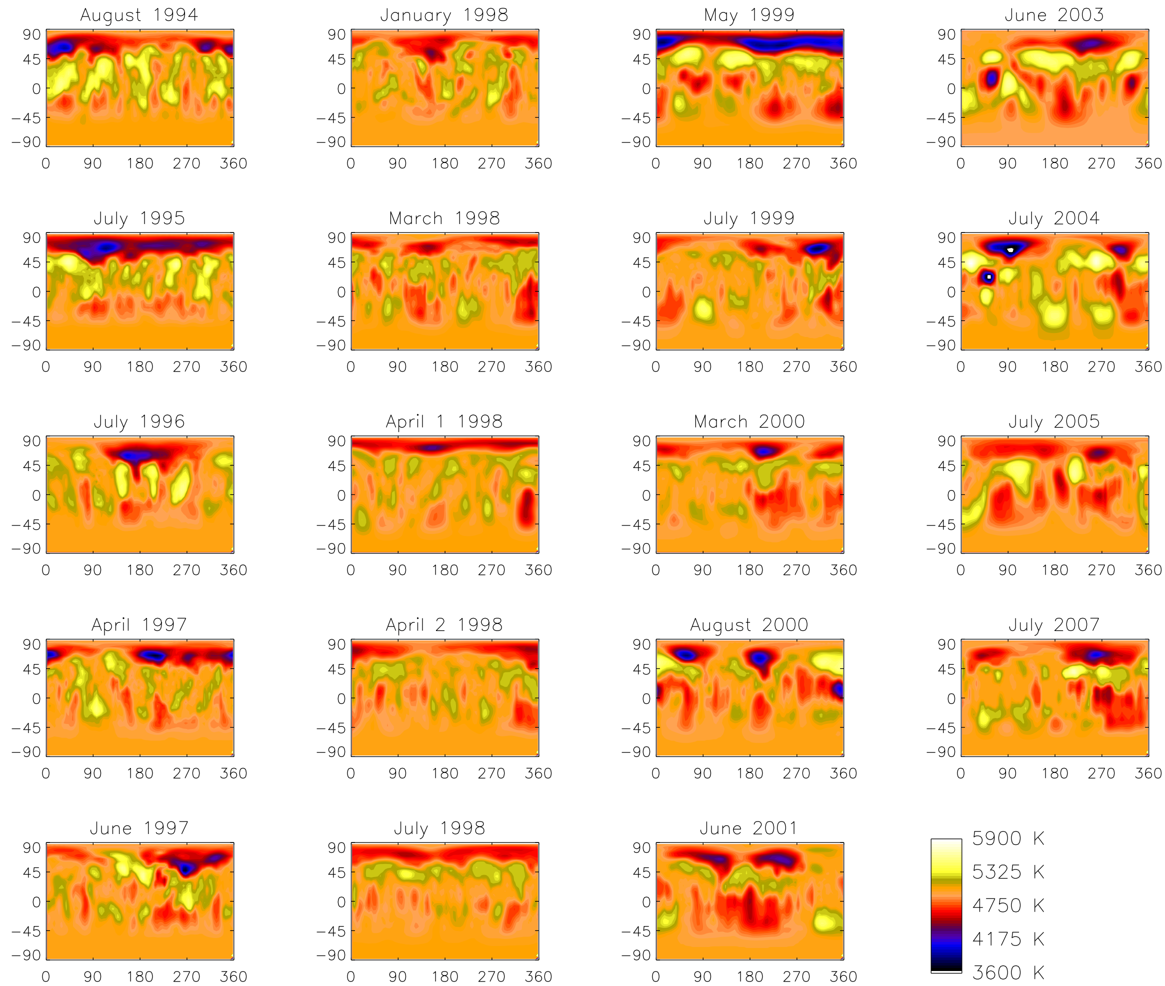

Fig. 1. Doppler images of FK Com from the years 1994–2007. In the maps the abscissa is the longitude in phases and the ordinate is the latitude in degrees. The maps for 1994–2003 have been published by Korhonen et al. (2007), and references there-in. The maps from 2004–2007 have not been published previously.

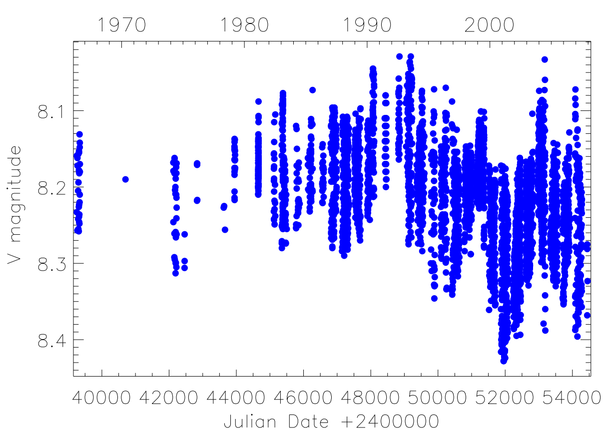

Fig. 2. All the available V band observations of FK Com.

Hereby high resolution, high signal-to-noise spectra at different rotational phases are used to measure the rotationally modulated distortions in the line-profiles. These distortions are produced by the inhomogeneous distribution of the observed characteristic, e.g., effective temperature, element abundance or magnetic field. Surface maps, or Doppler images, are constructed by combining all the observations from different phases and comparing them with synthetic model line profiles. Doppler imaging techniques were first used in the abundance mapping of Ap stars. Nowadays, Doppler imaging is more commonly used for temperature mapping of rapidly rotating late type stars (e.g., Berdyugina et al. 1998; Strassmeier & Rice 2003).

The spectra of FK Com were obtained in July 2004, 2005 and 2007 at the Nordic Optical

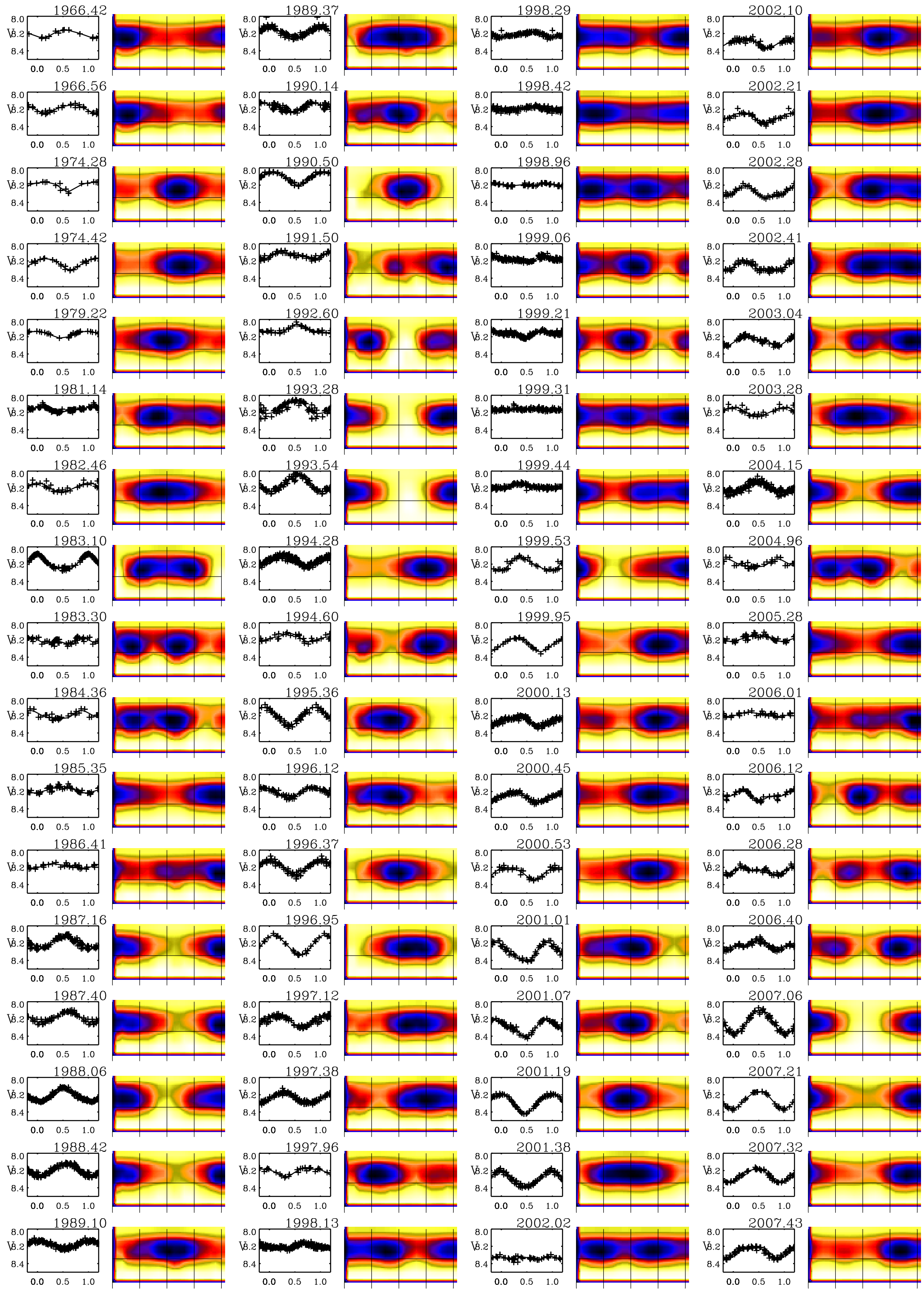

Fig. 3. The results from the light curve inversions. The darker colour indicates larger spot filling factor. The grid in the maps indicates the equator and 4 longitudes separated by 90 degrees. The observed (crosses) and calculated (line) V light curves are also presented.

Telescope using the SOFIN high-resolution échelle spectrograph. The resolving power was approximately 27 000. The phases for all the observations were calculated using the ephemeris obtained from 25 years of photometric observations, $HJD = 2,439,252.895 + (2^{\rm d}.4002466 \pm 0^{\rm d}.0000056)E$, referring to a photometric minimum and period calculated by (Jetsu et al. 1993).

The surface temperature maps were calculated using the Tikhonov Regularization code INVERS7PD, originally developed by N. Piskunov and modified by T. Hackman (Hackman et al. 2001). The stellar parameters adopted for Doppler imaging, and more details on the selection of the parameters, inversion technique and line-profile calculation were given by Korhonen et al. (2007). In the inversions the whole spectral region from 6416 Å to 6444 Å was used simultaneously, and the atmospheric line at 6433 Å was masked out from the inversions.

All the temperature maps for 1994–2007 are plotted in Figure 1. The new maps from 2004-2207 show very similar structures as seen in the earlier published maps. The spots are at high latitudes, and usually tend to concentrate on two longitudes. The temperature difference between the unspotted photosphere and the spot is approximately 1000 K. The largest temperature difference can be seen in the July 2004 map, where the difference is 1400 K.

3. LONG-TERM PHOTOMETRY

All the available V band observations of FK Com are plotted in Figure 2. Most of the data are from Jetsu et al. (1993); Strassmeier et al. (1997); Korhonen et al. (2001, 2002). New observations for the time period 2005–2007 are also shown. These observations were obtained using the Phoenix 10, Wolfgang and Amadeus automatic photometric telescopes in Arizona, USA (see Strassmeier et al. 1997; Granzer et al. 2001).

To investigate the changes in the light curves at different time periods, the data was divided into 68 subsets. The basis of the division was the phase coverage and the stability of the light curve during that time period. These light curves were used to obtain spot filling factor maps of the stellar surface with an Occamian approach inversion technique (Berdyugina 1998). The phases for the light-curves were calculated using the same ephemeris as for the spectra. One should note though, that the light curves represent one-dimensional time-series, so only the longitudinal information can be recovered from them. From that information, however, the possible active longitudes and the “flip-flop” phenomenon can be studied.

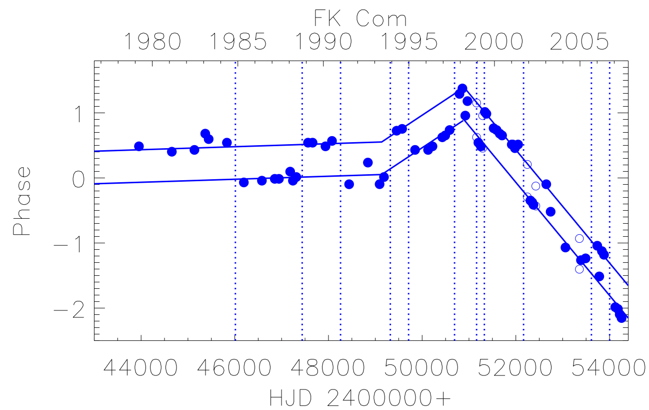

Fig. 4. Active longitudes on FK Com for the years 1980–2007. The phases of the main spots from photometry (blue circles) are plotted against the Julian Date. Open symbols denote a situation where two spots of similar strength are seen on the surface. Solid lines give the active longitudes determined from the photometry and the dashed lines denote the times of flip-flop events. This plot has been taken from Korhonen et al. (2004), but updated with the new data.

The individual light curves, together with the obtained spot filling factor maps, for the years 1966-2007 are shown in Figure 3. Looking at the spot phases in the filling factor maps, one can see that the spots migrate with time. In Figure 4 the phase of the main spot is plotted against the Julian Date. The spots tend to occur around the active longitudes and the active longitudes also migrate in phase. This implies that the 25-year average period used for the phase calculations does not represent the real spot rotation period for all the epochs.

4. COMBINING DOPPLER IMAGING AND PHOTOMETRY

Originally the active longitudes have been discovered from photometric observations which do not give very good resolution on spot locations. Thus it is interesting to compare the spot phases determined from Doppler images to those detected photometrically. In Figure 5 the spots determined from V band light-curves and the spots determined from the Doppler images are plotted against the Julian Date. The original plot has been presented by Korhonen et al. 2007, but we have up-dated it with the results from the new data for 2004–2007. Note that only the main active regions are shown in the plot, and that only the time period 1994–2007 (i.e., for which we have both the photometric observations and the Doppler images) is used.

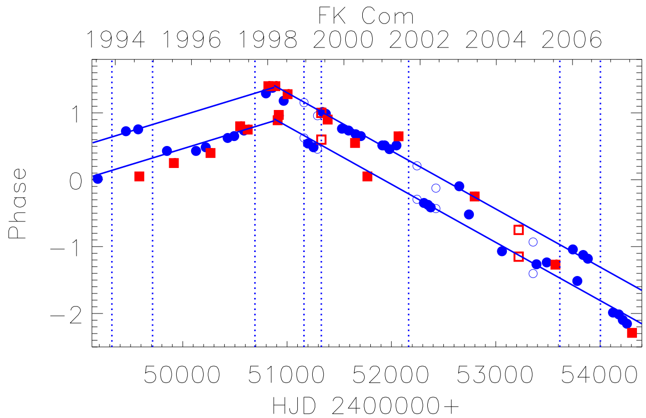

Fig. 5. As in Figure 4 but with the addition of the main spot phases from Doppler imaging (red squares). And only for the years 1994–2007 where both photometry and Doppler imaging results exist.

As can be seen, the spots on the Doppler images are located close to the earlier detected active longitudes. Especially the main spots correlate well with the active longitudes. The flip-flops are seen to happen periodically, but the exact time period between the events changes between about a year and more than three years. The longest time period without a flip-flop is 2002–2005. Still, it is possible that during the year 2003 the upper active longitude seen in the plot has been more active, and thus making the time between the flip-flops much shorter. What is also interesting to note is that close to the time of the flip-flops, e.g., around the two flip-flops in 1999, both the photometry and Doppler imaging show that both of the active longitudes are similarly active, as marked by the open symbols in the plot. This behaviour is expected to be seen close to a flip-flop event.

On the whole, the main active regions determined from the Doppler images confirm the existence of two permanent migrating active longitudes on FK Com, which were earlier detected using long term photometric observations. The new data from 2005 onwards confirms the behaviour seen earlier by (Korhonen et al. 2007).

REFERENCES

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. 1998, A&A, 340, 437
Chugainov, P. F., 1966, Inf. Bull. Variable Stars, 172, 1
Granzer, T., Reegen, P., & Strassmeier, K. G. 2001, Astron. Nachr., 322, 325
Hackman, T., Jetsu, L., & Tuominen, I. 2001, A&A, 374, 171
Järvinen, S. P., Berdyugina, S. V., Tuominen, I., Cutispoto, G., & Bos, M. 2005, A&A, 432, 657
Jetsu, L., Pelt, J., & Tuominen, I. 1993, A&A, 278, 449
Korhonen, H., Berdyugina, S. V., & Tuominen, I. 2002 A&A, 390, 179
__________. 2004, Astron. Nachr., 325, 402
Korhonen, H., Berdyugina, S. V., Hackman, T., Duemmler, R., Ilyin, I. V., & Tuominen, I. 1999, A&A, 346, 101
Korhonen, H., Berdyugina, S. V., Hackman, T., Strassmeier, K. G., & Tuominen, I. 2007, A&A, 476, 881
Korhonen, H., et al. 2001, A&A, 374, 1049
Merrill, P. W. 1948, PASP, 60, 382
Piskunov, N. E., Tuominen, I., & Vilhu, O. A&A, 230, 363
Strassmeier, K. G., Bartus, J., Cutispoto, G., & Rodonò, M. 1997, A&AS, 125, 11
Strassmeier, K. G., & Rice, J. B. 2003, A&A, 399, 315
Vogt, S. S., Penrod, G. D., & Hatzes, A. P. 1987, ApJ, 321, 496