Long-term photometric study of FK Com and HD 199178

Dinko Dimitrov, Kiril Panov
Institute of Astronomy, Bulgarian Academy of Sciences
dinko@astro.bas.bg
(Conference poster)

Abstract. The rapidly rotating active stars FK Com and HD 199178 are investigated using extensive long-term photometry. We look for periodicities in the long-term photometric behaviour of both stars, as well as for spots, using light curve modelling. The main result for FK Com is that the "flip-flop" phenomenon is a superposition of an oscillating process of activity and real and fast "flip-flops". For the oscillating component, we obtained a cycle of 5.8 yr. for FK Com and 4.2 yr. for HD 199178. Modelling of the light curves of both stars reveals a large high-latitude spot on each star and also smaller spots in the equatorial belt or at intermediate latitudes.
Key words: stars: activity – stars: individual: FK Com – stars: individual: HD 199178 – stars: starspots

Фотометрично изследване на FK Com и HD 199178

Динко Димитров, Кирил Панов

На базата на дълговременна фотометрия са изследвани бързовъртящите се активни звезди FK Com и HD 199178. Използвано е моделиране на кривите на блясъка за търсене на периодичности. Главен резултат за FK Com е, че явлението "flip-flop" е суперпозиция на осцилации на активността на звездата и реални бързи "скокове". За осцилациите определяме цикли от 5.8 години за FK Com и 4.2 години за HD 199178. Моделирането на кривите на блясъка за двете звезди показва голямо петно при високите ширини и по-малки петна при средните ширини и около екватора.

Introduction

FK Com and HD 199178 have long been known for their remarkable activity and extremely rapid rotation. Both stars belong to a small group, named after FK Com (Bopp & Rucinski 1981). FK Com is a G2III to G7III star, apparently a single giant with $v \sin i = 162.5$ km s^{-1}. Its chromospheric activity is similar to the chromospheric activity of the RS CVn stars. Photometric variability, attributed to rotational modulation by photospheric spots was first reported by Chugainov (1966), and he determined the photometric period, $P = 2\overset{\mathrm{d}}{.}412$. It is a common belief that the strong activity of FK Com is due to its rapid rotation.

Jetsu et al. (1991, 1993, 1994) revealed a new and interesting phenomenon: a "flip-flop" occurs in the FK Com activity, and it was attributed to a "switch-over" of activity between two active longitudes, apparently situated at opposite sites on the photosphere. Korhonen et al. (1999, 2000, 2001, 2002) conclude that the flip-flop is a rapid change in activity from one active longitude to the opposite one and not a movement of spots. This would also imply that minimum light would always occur around phases 0.0 and 0.5, assuming that the two active longitudes are permanent.

The star HD 199178 is another rapidly rotating giant of the FK Comae type stars (spectral class G5III–IV and $v \sin i = 80$ km s^{-1}). It is also apparently single with an upper limit to the radial velocity variation ± 2 km s^{-1}. The photometric period $3\overset{\mathrm{d}}{.}337$ was determined by Bopp et al. (1983). Jetsu et al. (1990) determined long-term cycles: 9.07 yr for the mean brightness and 2.84 yr for the changes in amplitude of rotational modulation. Other values for the photometric period have been suggested, making the situation even more complicated.

1 Observations

This study includes previously unpublished data for FK Com and HD 199178, obtained with the 60-cm telescope of the Rozhen National Astronomical Observatory and the

single-channel, photon-counting photometer. The comparison and check stars for FK Com are HD 117567 and HD 117876, and for HD 199178 we used HD 199206 and HD 199312. Care was taken in the reduction procedure to account for dead-time correction, extinction and the instrumental system corrections.

The Rozhen data for FK Com is added to the published photometry to construct a data set in V covering 1966 – 2005. For HD 199178, a data set was constructed, using published sources and Rozhen photometry, covering 1977 – 2004.

2 Light curve modelling

In order to look for the distribution of spots, we modelled the light curves for the whole data set, using the technique of the synthetic light curves, described by Eker (1994). In Table 1, input parameters of the modelling are listed, taken from published sources. Limb-darkening coefficients are taken from Al-Naimiy (1978) and a linear limb-darkening law was applied.

Table 1. Adopted parameters for light curve modelling.

Parameter		FK Com	HD 199178
$T_{\rm phot}$	[K]	5080	5450
ΔT	[K]	1200	1500
i	[°]	60	40
$V_{\rm max}$	[mag]	8.03	7.045
u		0.71	0.67
HJD_0	[days]	2439252.895	2442001.5
P	[days]	2.4002466	3.31925

The free parameters for constructing a light curve are: the number of spots, coordinates, and sizes of each spot. For a set of parameters, the solution for the light curve was obtained and the standard deviation σ computed. Then a number of iterations were done, changing parameters, until the desired fit is obtained with the minimal number of spots. For FK Com, 162 light curves from the total of 177 subsets were constructed. The analysis includes the light curves in 1979 – 2005, because data is scarce prior to 1979. For HD 199178, 148 light curves from the total of 169 subsets were constructed and analysed for 1977 – 2004. Individual light curves were determined in such a way that time resolution was achieved with reasonable phase coverage.

3 Data analysis and results

In Fig. 1, the O–C diagram is shown using the ephemeris of Jetsu et al. (1993):

$$HJD_{\phi_{min}} = 2439252.895 + 2\overset{\rm d}{.}4002466\,E \qquad (1)$$

for FK Com (left panel), and the ephemeris for HD 199178 (right panel):

$$HJD_{\phi_{min}} = 2442002.8 + 3\overset{\rm d}{.}30025\,E. \qquad (2)$$

The period chosen for HD 199178 is a "mean" one in the sense that a systematic drift of phases is avoided. In Fig. 3, we plotted the power spectrum of HD 199178 around the chosen period. The complexity of the diagram is obvious and due to both the data accuracy and the very real variations in the photometric period. This answers the question of why previous investigators published many different values for the photometric period of HD 199178. In a case with a variable period, such as HD 199178, the highest peak in the power spectrum diagram is not necessarily the best choice for the period.

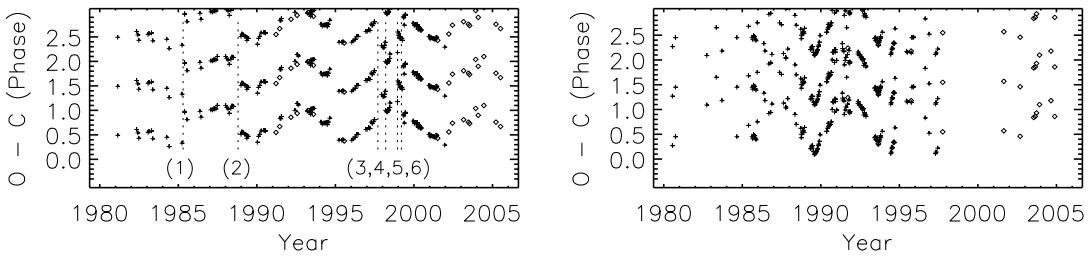

Fig. 1. Phases of photometric minima of FK Com (left) and HD199178 (right). Diamonds denote Rozhen data and crosses show published data. Vertical lines denote flip-flop events. The O – C diagrams are plotted three times in the ordinate, to make possible a better understanding of the variations observed.

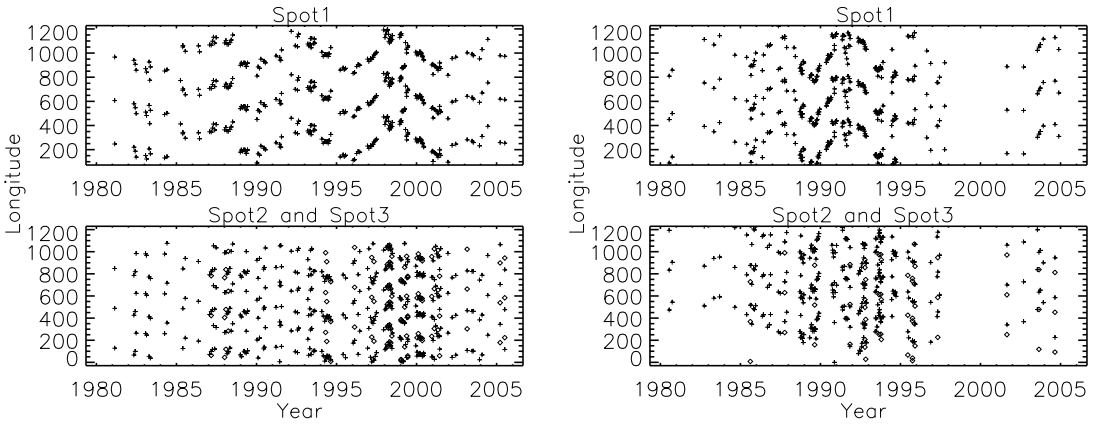

Fig. 2. Longitudes of Spot 1, Spot 2 – crosses, and Spot 3 – diamonds of FK Com (left) and HD 199178 (right). The same position of each spot is plotted three times in the ordinate, as in Fig. 1.

From Fig. 1 (left), it is apparent that the phase of minimum light (in V) is not always in position 0.0 or 0.5, as required by the simple flip-flop hypothesis. On the contrary, the variation in phases seems to be an oscillatory process, occasionally interrupted by sudden jumps (flip-flop No. 1 – 6) in phase (the case of FK Com).

For FK Com, the best solution is achieved with 3 spots. The largest Spot 1 is present in all 162 subsets (latitude generally higher than $70\,^\circ$, size $\sim 30 - 45\,^\circ$). Spot 2 is detected in 149 subsets, and Spot 3 only in 39 subsets. Spots 2 and 3 are much smaller than Spot 1 (each size is $\sim 5 - 25\,^\circ$). The modelling of HD 199178 reveals a large (size $15\,^\circ$ – $30\,^\circ$) Spot 1, lasting at least during 1980 – 2004 (Spot 1 is seen in 148 light curves). The best solution also includes two smaller spots (size $5\,^\circ$ – $20\,^\circ$): Spot 2 is detected in 120 light curves and Spot 3 is seen in only 19 light curves. In Fig. 2, we plotted the longitude of Spots 1, 2, and 3 for FK Com (left) and HD 199178 (right). From Fig. 2, it is apparent that only the longitudes of Spot 1 on both FK Com and HD 199178 show oscillatory behaviour, obviously corresponding to the respective O–C diagram in Fig. 1. This is a clear indication that Spot 1 is the dominant factor of the photometric behaviour of both FK Com and HD 199178. The longitude variation does

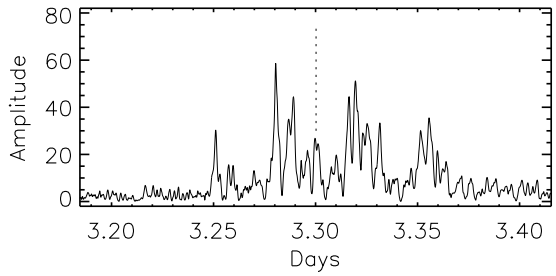

Fig. 3. Power spectrum of HD 199178. The vertical line denotes the photometric period, $P = 3\overset{\mathrm{d}}{.}30025$.

not necessarily imply that the spot migration proceeds only in the longitude direction. Latitudinal migration of Spot 1 and differential rotation could not be ruled out, as it would also result in a longitude variation. Evidence of differential rotation was found by Korhonen et al. (2002). However, because of insufficient latitudinal resolution of the synthetic light-curve method, it is not possible at present to distinguish between the two possibilities for Spot 1 movement: longitudinal migration or latitudinal migration with differential rotation.

We should also address the question of the stability of spots. Obviously, Spot 1 is not destroyed by differential rotation, and it has survived during the whole set of observations. Spots 2 and 3 are seen sporadically in the analysis.

A period search with the PERIOD04 program (Lenz & Breger 2005) was carried out with the long-term variation of minimum light, maximum light, mean light, the amplitude of rotational modulation, the O–C diagram, and the longitude variation of Spots 1 and 2. Fourier analysis, reveals a 5.8 yr cycle for the oscillating activity process for FK Com and a 4.2 yr cycle for HD 199178. The 5.8 yr cyclic variation of the FK Com O–C diagram follows the ephemeris (in days):

$$JD(\mathrm{O–C_{min}}) = 2439420 + 2118\,E \quad [\mathrm{days}]. \tag{3}$$

The 4.2 yr. cyclic variation in the O–C diagram of HD 199178 follows the ephemeris (in days):

$$JD(\mathrm{O–C_{min}}) = 2441460 + 1535\,E \quad [\mathrm{days}]. \tag{4}$$

References

Al-Naimiy, H. 1978, Ap&SS 53, 181
Bopp, B.W., & Rucinski, S.M. 1981, in Fundamental Problems in the Theory of Stellar Evolution, IAU Symposium 93, Sugimoto D., Lamb D.G., Schramm D.N. (eds.), Reidel, Dordrecht, p. 177
Bopp, B.W., Africano. J.L., Stencel, R.E., Noah, P.V., & Klimke. A. 1983, ApJ 275, 691
Chugainov, P.F. 1966, IBVS, No.172
Eker, Z. 1994, ApJ 420, 373
Jetsu, L., Huovelin, J., & Tuominen. I. et al. 1990, A&A 236, 423
Jetsu, L., Pelt. J., Tuominen. I., & Nations, H. 1991, The Sun and Cool Stars, Activity, Magnetism, Dynamos. Ed. I. Tuominen, D. Moss, & G. Rudiger, Springer, Proc. IAU Coll No 130, 381.
Jetsu, L., Pelt. J., & Tuominen. I. 1993, A&A 278, 449
Jetsu, L., Tuominen, I., Grankin, K. N., Mel'Nikov, S. Yu., & Schevchenko, V. S. 1994, A&A 282, L9
Korhonen, H., Berdyugina, S., Hackman, T., et al. 1999, A&A 346, 101
Korhonen, H., Berdyugina, S., Hackman, T., et al. 2000, A&A 360, 1067
Korhonen, H., Berdyugina, S., Strassmeier, K., et al. 2001, A&A 379, L30
Korhonen, H., Berdyugina, S., & Tuominen, I. 2002, A&A 390, 179
Lenz, P., & Breger, M. 2005, CoAst 146, 53