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Photometric Analysis of the Chromospherically Active Giant Star HD 86005

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Abstract. Photometric data, covering a span of two and a half years, have been analysed for the chromospherically active giant star HD 86005. It was found to undergo light variations and a photometric period of 89.0 ± 0.3 days was determined. Evidence suggests that these brightness variations are due to the rotation of unevenly distributed starspots.

Key words: chromospheric activity—late type giant—starspots—HD 86005

1. Introduction

HD 86005 has been observed at the Mt John University Observatory over a period of two and a half years as part of an extended photometric observation programme of possible active chromosphere stars. It was initially selected for observation due to the presence of several features characteristic of chromospheric activity, and was chosen for analysis because of the clear variability found in its photometric data.

The *Michigan Spectral Catalogue* (Houk 1975) lists it as spectral type K2 IIIp where the p indicates weak Ca II H and K line core emission. Bopp and Hearnshaw (1983) detected Hα emission above the continuum and Verma *et al.* (1983) measured a high infrared excess, which could partly be attributed to the presence of starspots. However, no radio emission was reported by Mutel & Lestrade (1985).

UBV photometric studies have been carried out by Grenier (1974) on one night, and by Bopp *et al.* (1986) over a period of nine nights. Udalski & Geyer (1984) conducted *UBV* $(RI)_C$ photometry over twelve nights, as did Cutispoto (1991) over fifteen nights. Bopp *et al.*, Udalski and Geyer, and Cutispoto found no variation in light levels over the span of their observations, although their values are different, suggesting some sort of long-term variability.

2. Observations

Differential photometric observations were carried out at the Mt John University Observatory between 1988 November and 1991 April, during which time 79 sets of

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BV(*RI*)*c* data points were obtained (Table 1). The comparison star used was HD 86034, while the check star was HD 85966.

Two telescopes were used for these observations, the 0.6 m Optical Craftsmen reflector (with an EMI9558B S20 photomultiplier tube) and the 0.6 m Boller & Chivens reflector (with an RCA C31034A GaAs photomultiplier tube). During each

Table 1. Mt John University Observatory photometric data for HD 86005.

HJD (2440000 +)	V	$(B-V)$	$(V-R)_C$	$(V-I)_C$	$V_{checkstar}$
7490.1056	7.305	1.301	0.696	1.271	7.448
7551.0722	7.298	1.312	0.728	1.252	7.434
7571.0453	7.301	1.298	0.713	1.290	7.452
7573.0480	7.284	1.312	0.736	1.301	7.438
7586.0112	7.344	1.294	0.697	1.272	7.449
7588.0892	7.332	1.297	0.700	1.278	7.450
7591.9843	7.351	1.291	0.703	1.282	7.447
7609.9278	7.345	1.295	0.730	1.317	7.452
7610.9265	7.343	1.310	0.730	1.315	7.443
7612.0509	7.332	1.301	0.728	1.312	7.441
7616.0363	7.339	1.284	0.709	1.291	7.449
7619.9413	7.326	1.289	0.714	1.265	7.439
7622.9755	7.326	1.285	0.706	1.280	7.451
7627.9659	7.296	1.300	0.723	1.296	7.434
7635.9537	7.306	1.292	0.697	1.274	7.435
7643.9646	7.313	1.286	0.712	1.267	7.447
7654.9936	7.294	1.287	0.701	1.263	7.436
7663.9182	7.305	1.305	0.703	1.266	7.440
7676.9469	7.318	1.318	0.732	1.307	7.455
7682.8899	7.336	1.302	0.729	1.316	7.441
7693.8552	7.354	1.302	0.705	1.300	7.446
7699.8888	7.328	1.310	0.725	1.306	7.442
7705.9132	7.321	1.302	0.740	1.316	7.451
7724.8597	7.332	1.290	0.710	1.294	7.441
7730.8272	7.316	1.300	0.699	1.283	7.448
7781.2273	7.391	1.301	0.713	1.321	7.449
7782.1500	7.358	1.317	0.688	1.290	7.427
7818.1102	7.312	1.301	0.707	1.277	7.448
7819.1078	7.315	1.298	0.707	1.284	7.425
7824.1581	7.307	1.301	0.688	1.279	7.453
7830.1069	7.301	1.303	0.693	1.273	7.441
7833.1254	7.301	1.295	0.696	1.275	7.460
7852.0633	7.331	1.326	0.700	1.284	7.428
7860.0660	7.366	1.302	0.726	1.320	7.470
7865.0782	7.363	1.303	0.712	1.296	7.444
7880.0711	7.322	1.303	0.699	1.290	7.439
7912.0348	7.306	1.281	0.708	1.288	7.449
7916.0733	7.285	1.288	0.695	1.271	7.437
7922.0688	7.299	1.277	0.702	1.281	7.459
7923.0696	7.280	1.284	0.698	1.260	7.445
7924.0682	7.277	1.302	0.695	1.266	7.447
7930.9573	7.287	1.298	0.698	1.276	7.448
7943.2069	7.337	1.299	0.712	1.300	

Table 1. Continued.

HJD (2440000 +)	V	$(B-V)$	$(V-R)_C$	$(V-I)_C$	$V_{checkstar}$
7943.9566	7.328	1.304	0.699	1.287	7.445
7949.9703	7.356	1.308	0.709	1.302	7.449
7955.9453	7.354	1.310	0.709	1.289	7.449
7964.9034	7.338	1.297	0.707	1.294	7.442
7968.9196	7.323	1.308	0.701	1.284	7.446
7971.9312	7.330	1.290	0.726	1.301	7.449
7986.0083	7.323	1.291	0.716	1.285	7.450
7989.9154	7.337	1.306	0.715	1.269	
7991.9217	7.318	1.293	0.709	1.284	7.447
7992.9300	7.318	1.293	0.701	1.294	7.444
7999.9352	7.313	1.289	0.706	1.281	7.445
8002.9409	7.307	1.283	0.705	1.288	7.446
8019.9506	7.306	1.292	0.705	1.284	7.443
8038.8698	7.359	1.302	0.702	1.304	7.447
8050.8907	7.318	1.320	0.733	1.298	7.424
8051.8869	7.329	1.299	0.718	1.291	7.465
8053.9093	7.370	1.293	0.752	1.326	7.434
8061.8853	7.314	1.292	0.722	1.310	7.452
8065.8725	7.328	1.303	0.701	1.297	7.447
8073.8546	7.342	1.298	0.706	1.320	7.461
8077.8790	7.350	1.297	0.720	1.307	7.461
8085.8205	7.341	1.292	0.717	1.289	7.449
8091.9205	7.314	1.314	0.693	1.296	7.459
8099.9075	7.317	1.269	0.694	1.301	7.464
8141.2183	7.342	1.294	0.688	1.285	7.447
8152.2213	7.320	1.307	0.706	1.290	7.457
8165.1956	7.309	1.278	0.715	1.301	7.412
8188.1345	7.303	1.293	0.707	1.278	7.459
8211.1200	7.326	1.283	0.670	1.242	7.420
8243.0471	7.294	1.258	0.697	1.283	7.431
8253.0733	7.300	1.292	0.709	1.271	7.453
8256.0223	7.313	1.275	0.716	1.288	7.462
8260.0539	7.308	1.290	0.708	1.281	7.451
8269.0386	7.304	1.290	0.704	1.287	7.452
8282.9907	7.295	1.293	0.696	1.280	7.476
8294.0253	7.275	1.291	0.689	1.256	7.446

observation, integrations lasting 5 or 20 seconds were repeated 3 or 2 times respectively, depending on the pass-band, with the integrations then being averaged. Two observations were obtained for each observing night and these were then averaged to give a nightly mean, which typically had a standard deviation error of $0^m.005$. The check star, however, had a standard deviation for all of the V data of $0^m.011$, so that one would expect the scatter in each data point of HD 86005 to be of this order.

It was found that the star exhibited variability over a time scale of around 100 days, with a peak-to-peak amplitude of approximately $0^m.07$ in V. This variability would not have been detected by the previous groups, assuming it was present during their observations, as their data spanned periods of two weeks or less.

3. Photometric period determination

Photometric periods in each pass-band were determined through the use of a FORTRAN program (Lawson 1990 *et al.)* based on the Lomb-Scargle method of applying a Fourier transformation to unevenly spaced data (Lomb 1976, Scargle 1982). The program produces a power spectrum in a specified frequency range, using a fixed frequency increment. Residual and phase data are also produced, as is a synthetic curve of the strongest frequency, and a facility is available to subtract this synthetic curve from the data so that a search for secondary frequencies can be made.

For HD 86005 significant power spectra peaks were identified for each of *B*, *V*,*R* and *I*, using the minimum possible frequency increment of 0.00001 cycles per day, and the results are given in Table 2. The average of these frequencies gives a photometric period for HD 86005 of 89.0 ± 0.3 days. Fig. 1 shows, as an example, the *V* data phased with its 89.6-day period, while Fig. 2 shows the power spectrum produced in *V*. Fig. 3 shows the power spectrum in *V* for the second harmonic (solid line), and the power spectrum in *V* after the second harmonic has been removed (dashed line).

Table 2. Fundamental and second harmonic frequencies for HD 86005, with, their phases and half-amplitudes.

Filter	Fundamental frequency	Phase	Half amplitude	First harmonic	Phase	Half amplitude
B	0.01119	4.68	0.029	0.02241	3.91	0.017
V	0.01116	4.57	0.023	0.02243	3.88	0.015
R	0.01126	4.68	0.017	0.02247	3.84	0.015
I	0.01132	4.54	0.012	0.02243	4.15	0.012
Average	0.011233	4.62		0.022435	3.95	
	± 0.000036	± 0.04		± 0.000013	± 0.07	
	(89.0 ± 0.3 days)			(44.57 ± 0.02 days)		

Phase, on a 0 to 2π basis, is the phase occurring on 1988 November 24 = HJD2447490.1056.

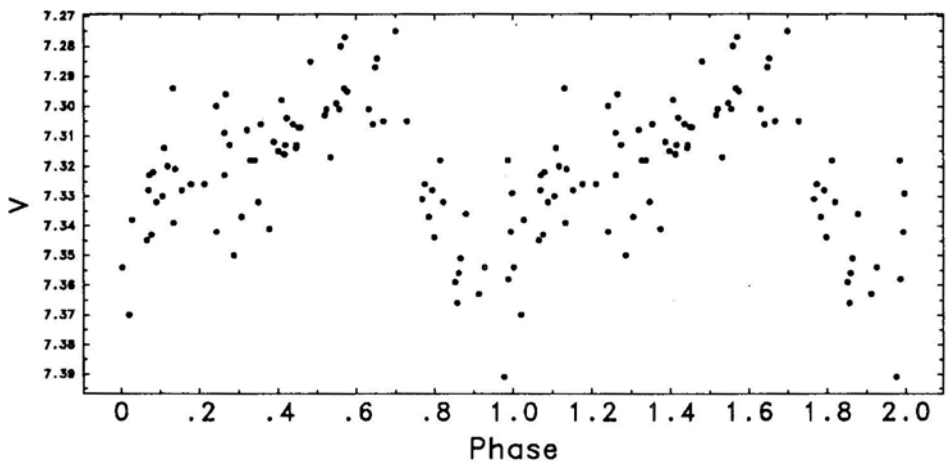

Figure 1. *V* data for HD 86005, phased with an 89.6-day period.

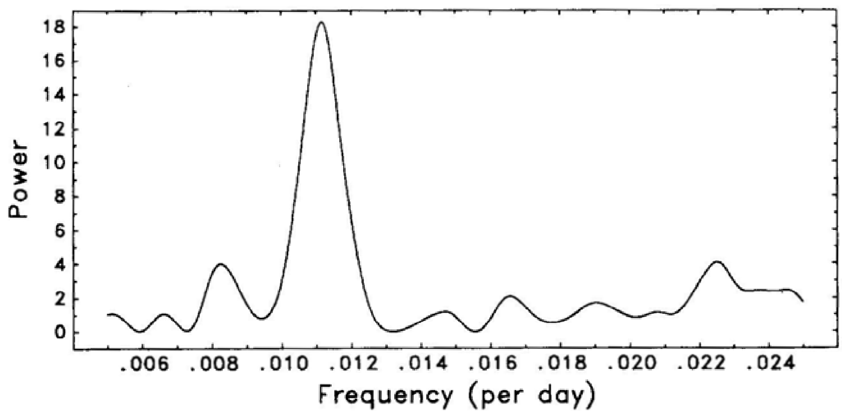

Figure 2. Power spectrum in *V* for HD 86005.

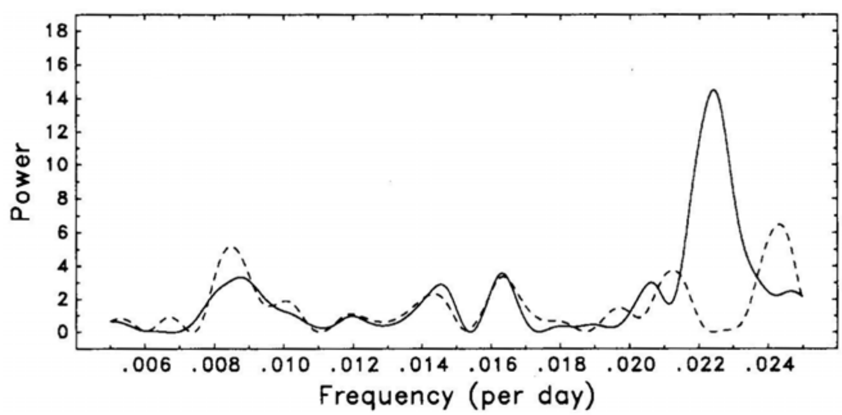

Figure 3. Power spectrum in *V* for HD 86005 obtained after the removal of the 89.6-day period (solid line), followed by removal of the second harmonic (dashed line).

The scatter in Fig. 1 has a standard deviation of $0^m.017$, which is larger than that expected from the observational errors. This is mainly due to the presence of a significant second harmonic. The residual in the data after the fundamental and second harmonic frequencies have been removed, has a standard deviation of $0^m.013$, which is much closer to the expected value. Additional scatter may be due to slight changes in period, amplitude or phase over the 9 cycles observed. Consideration of the first 36 data points in *V* resulted in a period of 87.3 days and a half-amplitude of $0^m.029$, while the final 43 points in *V* gave a period of 89.2 days and a half-amplitude of $0^m.020$. The mean *V* values were $7^m.325$ and $7^m.319$ respectively. It should be noted, however, that in each of the two cases the standard deviation of the scatter in the data was not significantly less than that resulting when all of the data was analysed together.

The peak-to-peak amplitudes of the light variations in each pass-band were measured from the synthetic curves composed of the fundamental and second harmonic sinusoids. The resulting amplitudes and error estimates are given in Table 3, along with the average values of *B, V*, *R* and *I* over the period of the Mt John observations.

Table 3. Average magnitudes of the Mt John data for HD 86005 and the amplitudes of the synthetic curves.

Filter	Average over observations	Peak to peak amplitude of synthetic curves
B	8.618	0.078 ± 0.005
V	7.322	0.066 ± 0.005
R	6·613	0.054 ± 0.005
I	6.033	0.043 ± 0.005

4. Discussion

The observed light variations of HD 86005 can be well explained by the application of a starspot model. If cool starspots were present on HD 86005 one would expect the amplitude of variation in the light curve to increase for shorter wavelengths, where the spots should radiate less light. This is indeed the case, as can be seen from Table 2. Furthermore, Fig. 4 shows a correlation between brightness and colour, with the star becoming bluer as it brightens.

The Mt John observations must have been carried out during a phase of high spot activity, such that at no time was an unspotted hemisphere facing Earth. This is supported by the fact that the light curve in Fig. 1 is not flat topped, as would be the case if no spots were visible over a time scale of several days. It is possible that the values obtained by Grenier (1974) and Bopp *et al.* (1986) correspond to the unspotted colour indices of the star, as their observations are the brightest of the five photometric studies, and their values agree remarkably well despite being obtained approximately 15 years apart. It is unfortunate that no $(V - R)$ or $(V - I)$ values are given by Grenier or Bopp *et al.,* since known unspotted colour indices for HD 86005 would have enabled a quantitative starspot model to be applied.

The results of Grenier (1974), Udalski & Geyer (1984), Bopp *et al.* (1986) and Cutispoto (1991) are all significantly brighter than any of the Mt John observations. It is thus clear that for this to be due to starspots a change in the number of spots, or a redistribution of spots, must have occurred at least in the couple of years prior to the Mt John observations, if not at other times. It may be that an activity cycle is present, such as that observed for other chromospherically active stars (Baliunas & Vaughan 1985).

Comparison between the colour indices obtained by the various groups reveals some anomalies. The colour indices are given in Table 4 and it can be seen that they are remarkably constant in colour as the star becomes fainter. Using a simplistic starspot model with no energy redistribution, one would expect a star to become redder as it becomes fainter if the area of the photosphere covered by starspots is increasing. This is not the case for HD 86005. Indeed, at the Mt John light maximum the $(B - V)$ colour index is bluer than that of Bopp *et al.* (1986), although this could lie within the error bars, as is the $(V - I)_c$ index for all of the Mt John observations. If a starspot model were applied at the Mt John light maximum, where ΔV between the Mt John value and the Bopp *et al.* value is marginally greater than ΔR, then hot spots would result.

In addition, there appears to be an excess of UV light. The $(B - V)$,$(V - R)_c$ and $(V - I)_c$ indices correspond roughly to a K3.5III star (Bessell 1979), whereas the

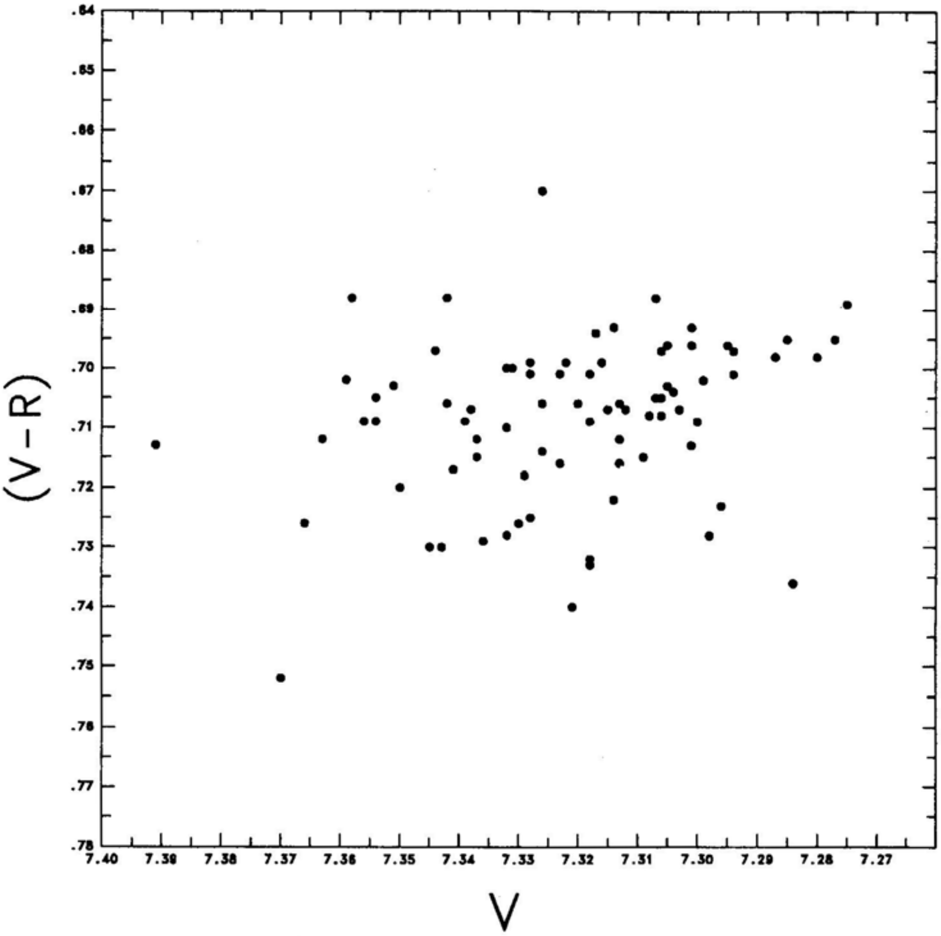

Figure 4. Colour correlation with brightness for HD 86005.

($U - B$) index is that for a K1 III star (Johnson 1966). As Cutispoto (1991) notes, this could be due to the presence of an early type companion, but in view of the fact that UV excess is a well known feature of chromospherically active stars (Hall 1976) this is probably not the only plausible explanation.

Chromospherically active stars with periods greater than that of HD 86005 have

Table 4. *UBV*(*RI*)*c* photometry of HD 86005.

	V	$(U-B)$	$(B-V)$	$(V-R)_C$	$(V-I)_C$
Grenier (1974)	7.18	1.09	1.30		
Bopp *et al.* (1986)	7.180	1.020	1.296		
Udalski & Geyer (1984)	7.230	1.026	1.307	0.711	1.347
Cutispoto (1991)	7.25	1.03	1.32	0.71	1.36
Mt John at maximum light	7.29		1.29	0·70	1.28
Mt John average	7.322		1.296	0.709	1.289
Mt John at minimum light	7.36		1.30	0.72	1.30

been observed (Fekel *et al.* 1986; Hall *et al.* 1990) but even so HD 86005 has an exceptionally slow rotation period compared to most other active chromosphere stars (Hartmann 1980; Baliunas & Vaughan 1985; Fekel *et al.* 1986). It may be that this is why only weak Ca II H and K core emission is present, and why the amplitude of light variation is at the lower end of that observed in other active chromosphere stars, where the amplitude can range up to $0^{m}.5$ in V (Hartmann 1980).

It is possible that HD 86005 may belong to the group of FK Comae stars, which are single late-type giants exhibiting strong chromospheric activity (Bopp & Stencel 1981). However in this case the star should be a rapid rotator, which is not observed for HD 86005. It seems that HD 86005 perhaps best belongs to the group, identified by Fekel *et al.* (1986), of medium to rapidly rotating single G8–K2 giants which exhibit moderate chromospheric activity.

5. Conclusion

The analysis of a two and a half year span of photometric $BV(RI)_c$ data has resulted in evidence that suggests that starspots are the cause of the observed 90-day light variations of HD 86005. The detection of this 90-day period demonstrates the desirability of long term photometric observations, as short term observations may result in a star being classified as non-variable when in fact that is not the case. The colour variations predicted by a starspot model were observed in the Mt John data. However, a simplistic starspot model is inadequate to explain the observed constancy of the colour indices of HD 86005 as the star brightens and modifications to the model would be required to explain this feature.

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